06

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COMMITTEE.

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CONTENTS.

On Micro-tremors.

By

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With Pls. I-III.

Introduction. The non-seismic vibrations of the ground called "pulsatory oscillations" are small slow movements with periods generally of about 4 or about 8 sec., possibly all over the world. These oscillations, which are most markedly shown at Tokyo, Osaka, and other places situated on an extensive plane of new formation, and also probably at mid-ocean islands*, have sometimes a double amplitude of 0.5 mm or more. What I propose here to term *micro-tremors* are those insensible movements of the ground, whose period is usually less than 1 sec., and whose amplitude is much smaller than that of the pulsatory oscillations. In short, the micro-tremors are, whatever their origin may be, extremely minute vibrations of a nature similar to that of the movements composing the macro-seismic, or sensible, part of the earthquake motion proceeding from a near centre of disturbance.

The diagrams furnished by Omori horizontal tremor recorders and tromometers‡, of 90 to 300 times magnifications, set up in

* As shown by the Omori Hor. Pend. Tromometer observation at the meteorological observatory of Hachijo-jima, an island belonging to the Fuji volcanic chain.

‡ These instruments are improved forms of those described in the *Publications*, No. 18, and the *Bulletin*, Vol. I, No. 4.

Osaka and Tokyo indicate the micro-tremors often quite distinctly. For the sake of clearness, however, some photographic enlargements of the original records are reproduced in Pls. I to III. I give next the results of some preliminary investigations on micro-tremors.

Observation at Hitotsubashi (Tokyo). The observation at Hitotsubashi was made with a horizontal pendulum tromometer of 100 times magnification. The maximum double amplitude in the EW component was about 0.0015 mm, the average periods' each deduced from 100 consecutive vibrations, being as follows :—

Date (1907).		Average Period (EW Component).	
July	5-6	0.80 sec.	
"	"	0.91	
"	"	1.01	
Oct.	29-30	0.84	
"	30-31	0.83	
"	"	0.82	.... *Mean*, **0.83** sec.
Nov.	22-23	0.77	
"	"	0.88	
"	28-29	0.60	
"	"	0.82	

The mean period of micro-tremors at Hitotsubashi is thus seen to be 0.83 sec. To compare these tremors with the quick vibrations actually occurring in an earthquake, I give in Pl. I a part of the tromometer record for July 5 and 6, 1907, which was photographically enlarged 8 times and thus magnifies 800 times the movements of the ground, with a time scale of 197.4 mm for

1 minute. The seismic disturbance shown in the diagram consists of the preliminary tremor and the earlier part of the principal portion of the earthquake of July 6, 1907, which originated under the sea about 900 km to the NE of Tokyo and was felt strongly at the coast of Nemuro and Kushiro (Hokkaido). In Tokyo, the shock was slight, and the total duration about 2 hours, the time of occurrence being 0h 48m 07s A.M. According to Pl. I, the quick vibrations in the preliminary tremor, which lasted 90.0 sec. (the commencement is marked a), were as follows* :—

Average $T=0.77$ sec., Max. $2a=0.074$ mm.

The active vibrations at the commencement (marked b), of the principal portion was as follows :—

Average $T=0.88$ sec., Max. $2a=0.36$ mm.

Thus the mean period of the macro-seismic movements was in this case about 0.83 sec., which happens to be identical with the average period of the micro-tremors (at Hitotsubashi) as given in the foregoing table. Especially, the larger and slower ones of these tremors, as those marked e and f (Pl. I), will be seen to be similar in nature to the prominent vibrations occurring in the principal portion (b) of the earthquake. Finally, for the sake of reference, I may state that, according to the result of the macro-seismic measurement in Tokyo‡, the average period at Hitotsubashi was found to be 0.77 sec., this characterizing the ordinary earthquake vibrations. The period of strong shocks at the same place is a little longer and equal to 0.9 to 1.0 sec.

Observation at Hongo (Tokyo). The micro-tremors at Hongo are probably somewhat smaller than those at Hitotsubashi,

* T and $2a$ denoting as usual the complete period and the double amplitude, respectively.

‡ The "Publications," No. 11, p.p. 51 and 52.

the max. 2a in the EW component being about 0.0011 mm. Pl. II is a part of the diagram for Jan. 23, 1908, furnished by an EW component horizontal tremor-recorder with an original pointer multiplication of 300 times, enlarged photographically 8 times, the resultant magnification being thus equal to 2,400, with a time scale of 835 mm for one minute. The average periods of the micro-tremors each deduced from 200 consecutive vibrations, were as follows:—

Date (1908).		Average Period (EW Component).
Jan.	20–21	0.28 sec.
„	22–23	0.28
„	24–25	0.28
„	„	0.32
Mean.		**0.29** sec.

The mean value of the period of the micro-tremors was in these cases 0.29 sec., which is not much different from those of the quick vibrations and ripples occurring at Hongo in actual earthquakes. Thus, according to the macro-seismic measurement at Hongo*, we have the following results:—

Average period of	max. quick horizontal vibrations	= 0.26 sec.
„	superposed horizontal ripples	= 0.20 „
„	max. quick vertical vibrations	= 0.25 „

Observation at Osaka. The horizontal tremor-recorder with a multiplication of 90 times, at the Osaka Meteorological Observatory (Director, Mr. N. Shimono,) indicates micro-tremors much more distinctly than in Tokyo, the max. $2a$'s in the EW

* See the *Publications*, No. 11, p.p. 53–55.

and NS components being each about 0.008 mm. Pl. III is a part of the record for Dec. 28, 1907, enlarged photographically 7.8 times, so that the resultant magnification is about 700 times. The average period of micro-tremors was as follows :—

Date (1907).		Average Period*.			
		EW Component.		NS Component.	
Nov.	18–19	0.81 sec.	(100)	0.90 sec.	(100)
„	„	0.88	(100)	0.95	(100)
„	21–22	0.77	(100)	0.88	(100)
„	„	0.80	(100)	0.84	(100)
Dec.	20-21	0.74	(200)	0.87	(200)
„	21–22	0.68	(200)	0.89	(200)
„	22–23	0.74	(200)	0.84	(200)
Mean..........		**0.76**		**0.88**	

The average period of the micro-tremors obtained by taking the mean from the two horizontal components is 0.82 sec. In this connection it is interesting to note that the ordinary seismograph observation at the same observatory of the vibrations caused by a powder explosion at a distance of 5 km in one of the suburbs of Osaka indicated also similar periods, as follows† :—

Vertical motion....Aver. $T=0.75$ sec. (Max. $2a=0.40$ mm);
EW „ .... „ $=0.83$ „ („ $=0.48$ „);
NS „ .... „ $=0.82$ „ („ $=0.24$ „);

the mean value of the period of the horizontal motion being thus

* The numbers of consecutive vibrations, from which the average period was deduced is in each case indicated by the figures 100 or 200, enclosed within brackets.

† An account of the vibrations caused by the powder explosion at Fuku-mura, near Osaka, is given by the present author in the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 57.

0.82 sec. In the cases of the strong Inland Sea earthquake of June 2, 1905, and two of its after-shocks, the period of the maximum horizontal motion at Osaka was about 1.0 sec.

Conclusion. The micro-tremors at Tokyo and Osaka seem to occur chiefly during the day time, and may be due to traffic and other artificial causes, and also to the impact of winds against the ground. At any rate, however, their periods seem to be nearly identical with those of the ordinary sensible, or macro-seismic, vibrations at the respective places of observation, just as the period of the pulsatory oscillations are found to be similar to some component movements occurring in actual earthquakes. It is needless to remark that both pulsatory oscillations and micro-tremors form interesting subjects of study, especially in connection with local earthquakes.

Tokyo. Jan., 1908.

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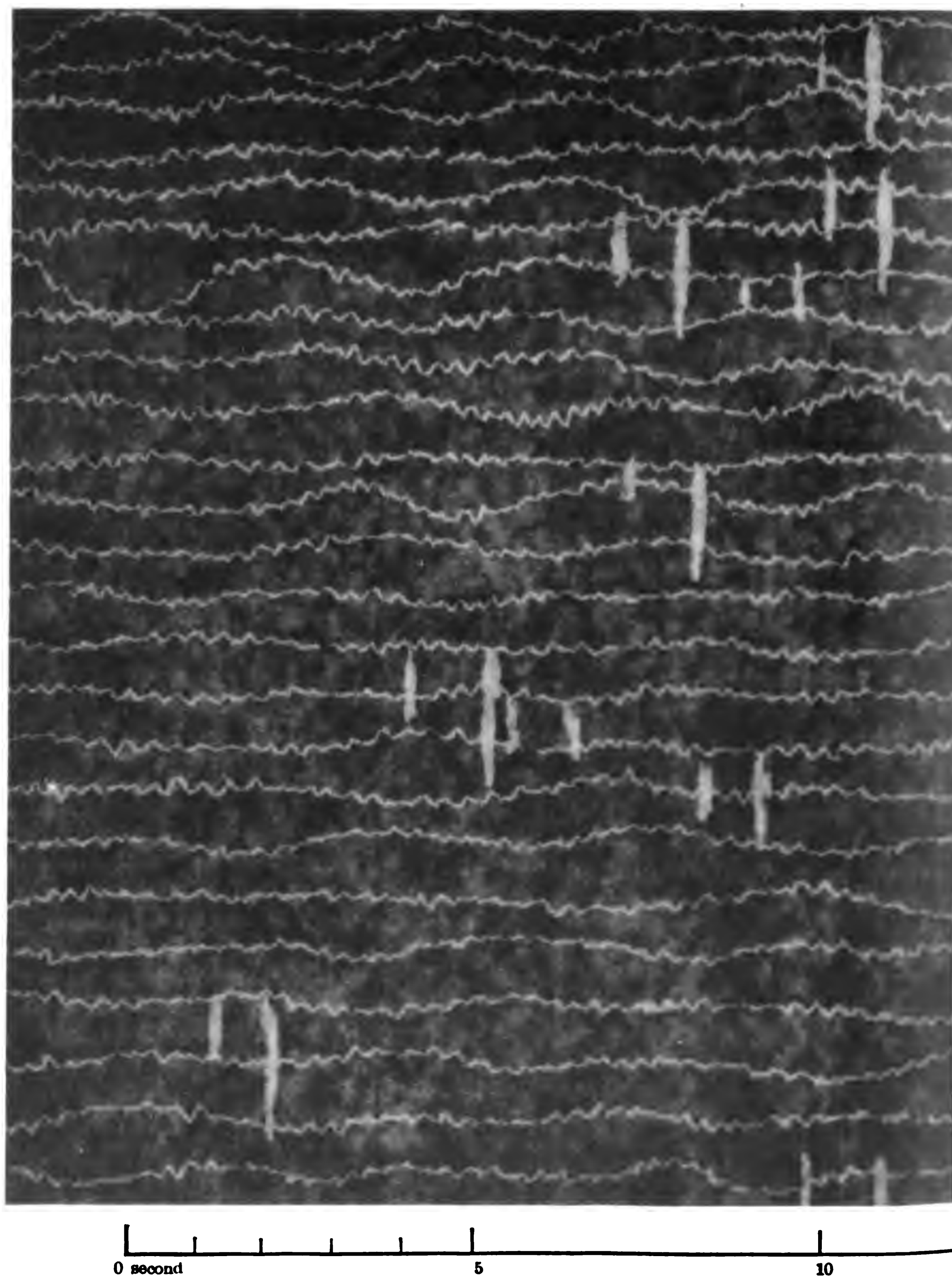
PL. I.

Omori Tremor Recorder Diagram, show

Magnification=2,400. (Original Multiplication=300).]



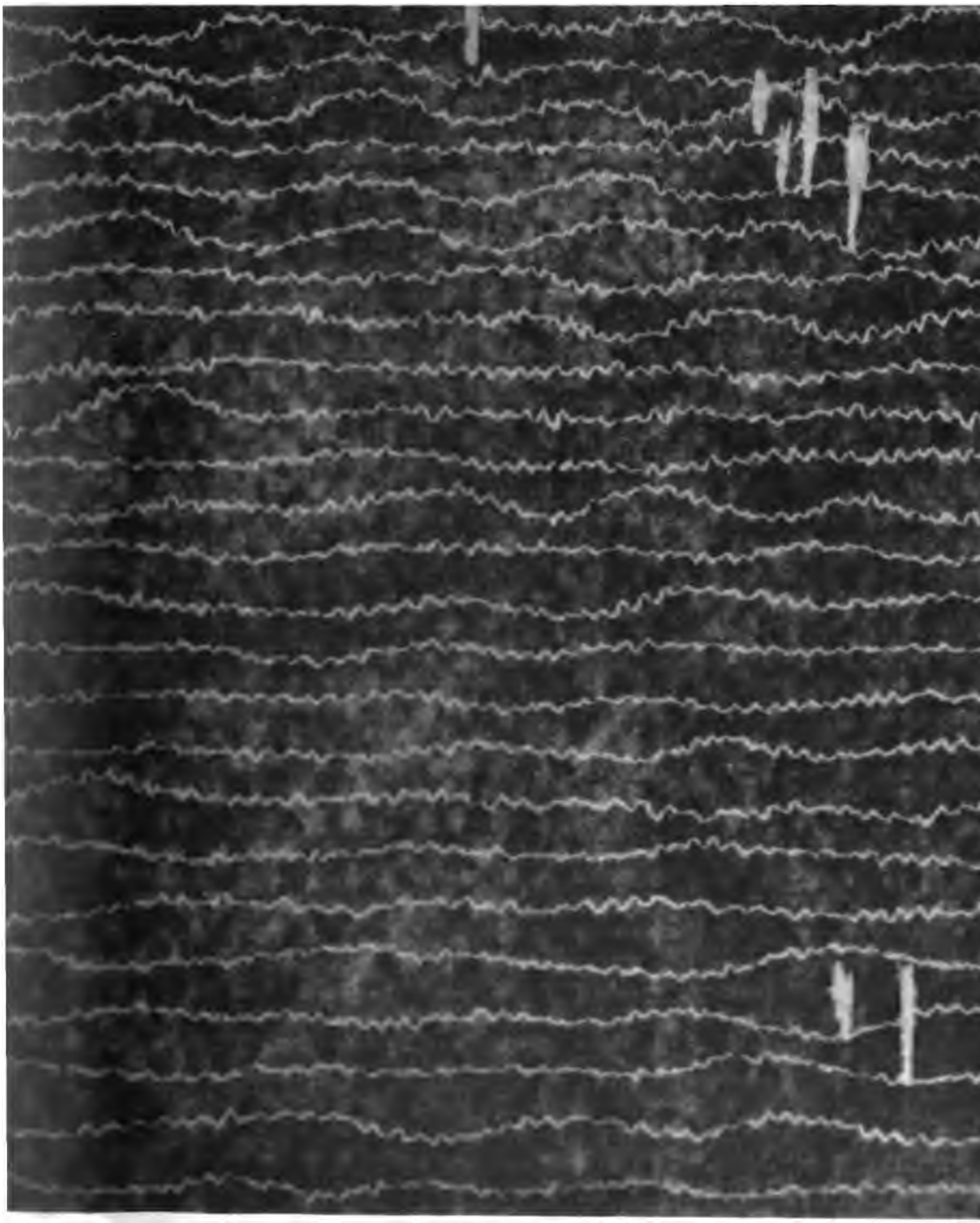
ving Micro-Tremors.

Pendulum Period=4.7 sec.

Hongo (Tokyo), Jan. 23, 1908.

EW Component.

Slower movements are pulsatory oscillations.

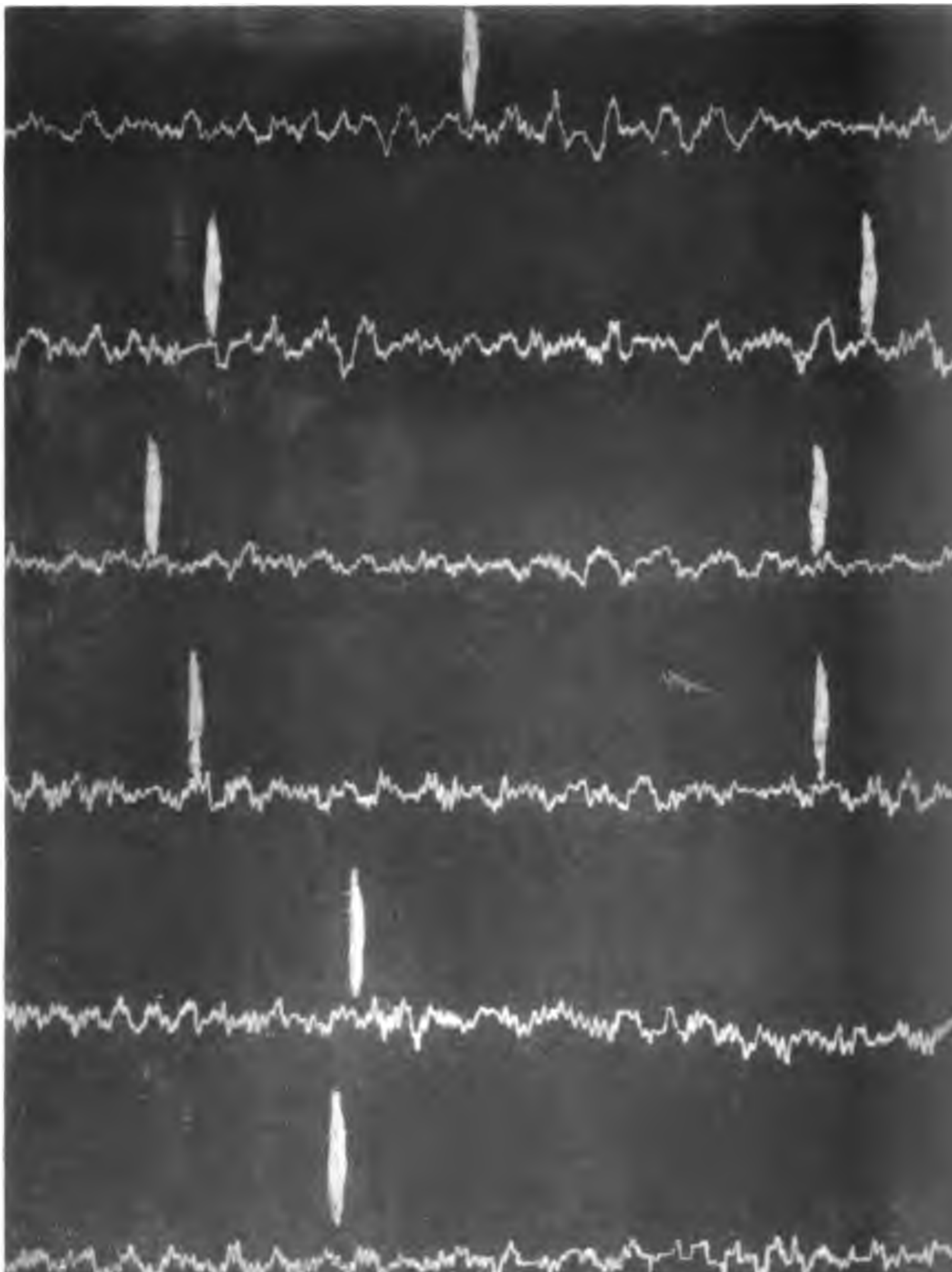


Time scale.

15 20 25 second

Omori Tremor Recorder Diagram, showing

Magnification=700. (Original multiplication=90). Pend

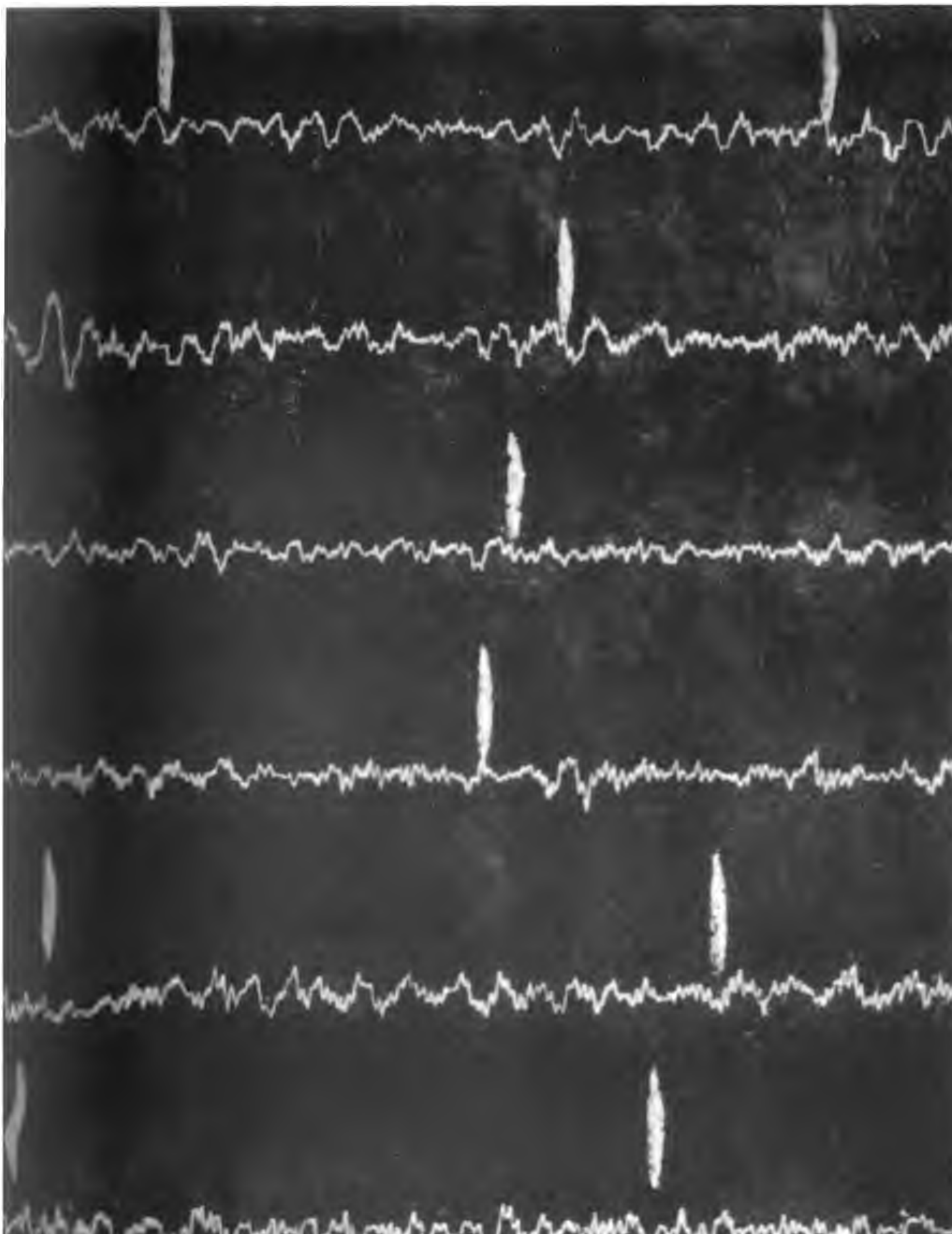


Micro-Tremors.

Osaka. Dec. 28, 1907.

:lum Period=4 sec.

NS Component.



Note on the Tokyo Earthquake of Nov. 22, 1907.

By

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With Pls. IV-VI.

The earthquake of Nov. 22, 1907, at 2h 17m A.M., was one of the strongest felt in Tokyo since the semi-destructive shock of June 20, 1894. The disturbance, which caused no damage, was a local one, and the severity of motion in Tokyo was partly due to the proximity of the latter to the earthquake origin. The total duration of the records furnished by the teleseismographs in Tokyo was only 24 min., while that in Kobe, where the shock was insensible, was 12 min.

Area of disturbance. As shown in Fig. 1 (Pl. IV), the earthquake was sensible within a land area about 75 km in length and 300 km in width. The area of moderate motion was nearly circular, with a mean diameter of about 320 km. Again, the area of strong motion is a small ellipse in the NW-SE direction, whose major and minor axes are respectively about 130 and 85 km. in length. It may be remarked that the south-eastern half of this meizoseismal ellipse coincides with the alluvial plain of Musashi, where the motion is much intensified owing to the softness of the ground; the centre of the ellipse not necessarily corresponding to the real earthquake epicentre.

The position of the latter seems in fact to be much eccentric and near the north-western end of the major axis, as considered in the next §.

Duration of preliminary tremor and position of epicentre. The durations of the preliminary tremor observed instrumentally at Tokyo and 7 other stations were as given in the following table.

Name of Station.	Latitude.	Longitude.	Duration of the total preliminary tremor.	Calculated epicentral distance.
			sec.	km.
(i) Tokyo.	35°43′ N	139°46′ E	7.5	**92**
Mito.	36 23	140 28	10.0	110
Tsukuba.	36 13	140 06	10.0	110
(ii) *Mean*	....	....	10.0	**110**
Miyako.	39 38	141 59	50.0	400
Ishinomaki.	38 26	141 19	42.5	347
(iii) *Mean*	....	....	46.3	**374**
(iv) Nagano.	36 40	138 10	21.8	**197**
Kobe.	34 41	135 11	48.6	391
Osaka.	34 42	135 31	50.0	400
(v) *Mean*	....	....	49.3	**396**

The duration of the preliminary tremor has been determined in the usual way from the different seismograms, with the exception of those obtained in Tokyo. The phase in question for the latter place has been taken in regard to the vibrations of macroseismic nature.

The figures in the last column of the above table have been calculated by the formula, x km$=7.27$ y sec.$+38$, in which x and y are respectively the epicentral distance and the duration of the preliminary tremor. Drawing on the map (Fig. 1) five circles with radii equal to the calculated distances of (i) to (v) about the respective positions as centres, we see that four of these meet near one another in the southern part of the province of Kotsuke. The probable position of the epicentre, indicated in the figure by a small cross ($\times$), is situated in the northern part of the province of Musashi, namely, at about latitude $36°\frac{1}{4}$ N, and longitude $139°\frac{3}{4}$ E, at a distance of about 55 km to the north-west of Tokyo.

Observation in Tokyo. Time of Occurrence = 2h 17m 35s A.M.

Initial slow displacement. The seismograms furnished by the long-period horizontal pendulum instruments in Tokyo, three of which are reproduced in Pl. VI, are interesting in showing apparently no preliminary tremor, but beginning at once with a large slow vibration of period of about 7.5 sec., followed by a number of the proper pendulum oscillations. The initial displacements in the EW and NS directions, meaned from the different diagrams, are as follows :—

Motion toward East = 3.3 mm.
„ „ North = 3.2 „
Resultant displacement = 4.6 mm ; Direction, N 46° E.

Thus it will be observed that the direction of the initial (slow) motion was in this case approximately perpendicular to the line joining Tokyo with the earthquake origin, the vibration probably belonging to the category of the transverse wave*. A circumstance,

* See also an account of the earthquake of Jan. 21, 1906, which originated off the south-eastern coast of the Main Island. The *Bulletin*, Vol. I, p. 145.

which gives support to this latter supposition, is that the horizontal pendulum diagrams obtained at the other stations, whose epicentral distances were greater than that of Tokyo, showed no distinct slow vibration at the commencement, the preliminary tremor being generally well marked, due possibly to the slower transit rate and the consequent retardation of the transverse wave. The total duration of the earthquake motion in Tokyo was 24 min.

The results of studies on the nature of the vibrations occurring at the commencement of an earthquake, observed near the origin of disturbance, will be published in the *Bulletin* from time to time, a general discussion on this subject being reserved for a future occasion.

Macroseismograph record obtained at Hitotsubashi (Tokyo). Fig. 2 (Pl. V) gives the preliminary tremor and the earlier and most active part of the principal portion of the earthquake motion as recorded by an ordinary Gray-Ewing-Milne type seismograph, which magnifies the EW, NS, and vertical components 3, 4, and 2 times respectively. It will be observed that in this macro-seismogram, which does not show the slow vibrations existing in the earthquake motion, the preliminary tremor is well defined, the principal portion beginning with conspicuous movements of large amplitude. In the following description of the seismogram, the complete period and the range of motion (double amplitude) are denoted by the symbols T and $2a$ respectively.

Horizontal Motion.

The motion was sensible for about 2 min.

Preliminary tremor. The movements were as follows :—

(NS) $T = 0.85$ sec., Max. $2a = 1.00$ mm.
(EW) $T = 0.82$ „ Max. $2a = 0.73$ „

Principal portion. The motion was about 3 times greater in the NS than in the EW component, this being contrary to what is usually the case with strong Tokyo earthquakes, in which the EW component greatly predominates. For the first 2.3 sec., the vibrations were comparatively small and principally in the NS component :—

(NS) $T = 1.04$ sec., Max. $2a = 9.5$ mm.
(EW) $T = 0.17$ „ Max. $2a = 1.3$ „ (ripples).

Then the motion became much larger, there being 4 displacements (marked, in Fig. 2, respectively *cd*, *de*, *ef*, and *fg*) composing 2 vibrations as follows :—

1st displacement....	11.3 mm toward N, 4.5 mm toward W; Resultant $2a = 12.3$ mm, toward N22°W.
2nd „	16.3 mm toward S, 5.3 mm toward E; Resultant $2a = 170$ mm, toward S18°E.
3rd (Max.) „	22.0 mm toward N, 7.7 mm toward W; Resultant $2a = 23.3$ mm, toward N19°W.
4th „	9.3 mm toward S, 7.3 mm toward E; Resultant $2a = 11.8$ mm, toward S38°E.

The above 4 displacements, together lasting 2.0 sec., constituted the most active part of the earthquake; the 2nd and 3rd displacements forming the maximum vibration of $2a =$ **23.3** mm, and period = **0.95** sec., whose maximum acceleration was 510 mm per sec. per sec. As the mean direction of motion was N24°W–S24°E, these movements took place approximately parallel to the line joining the earthquake origin with the observing place and are due probably to the longitudinal wave. The subsequent motion was smaller, but continued active for about 1m 12s, the period being as follows :—

$$\left.\begin{array}{ll}\text{(NS)} & T = 0.79 \text{ sec.} \\ \text{(EW)} & T = 0.81 \;\;\text{,,}\end{array}\right\} \text{average, } \mathbf{0.80} \text{ sec.}$$

Vertical Motion.

Preliminary tremor. The motion was very small.

Principal portion. The motion which was small during the first 3.5 sec., was active during the next 18 sec., and consisted of the following vibrations :—$T = 0.47$ sec., Max. $2a = 1.3$ mm.

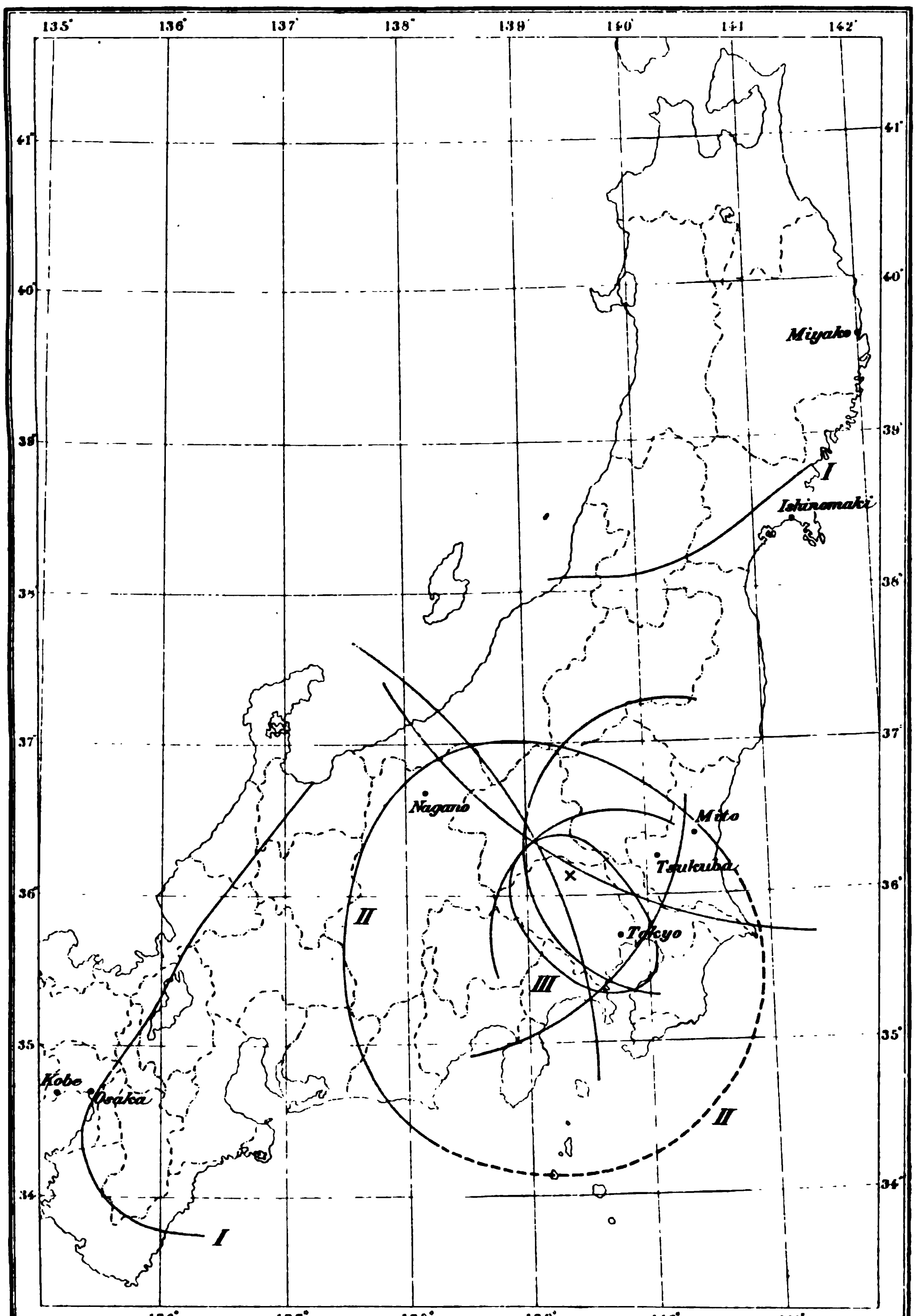
Observation at Hongo (Tokyo). The maximum macro-seismic motion at Hongo was $2a = 10.4$ mm, $T = 0.7$ sec., nearly in the NS direction.

Fig. 1. Tokyo Earthquake of Nov. 22, 1907.

I, II and III are respectively the boundaries of the areas of *slight*, *moderate*, and *strong* movements.

Arcs in red are drawn about the different places as centres with radii calculated from the duration of the preliminary tremor.

(×)......Probable Position of the Earthquake Origin.



------ *Boundary of provinces*

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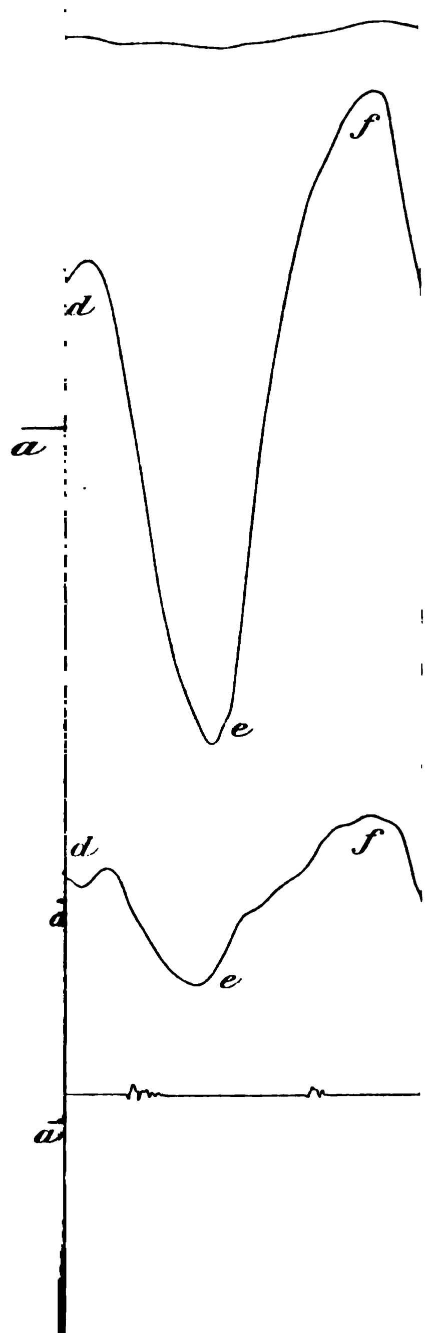


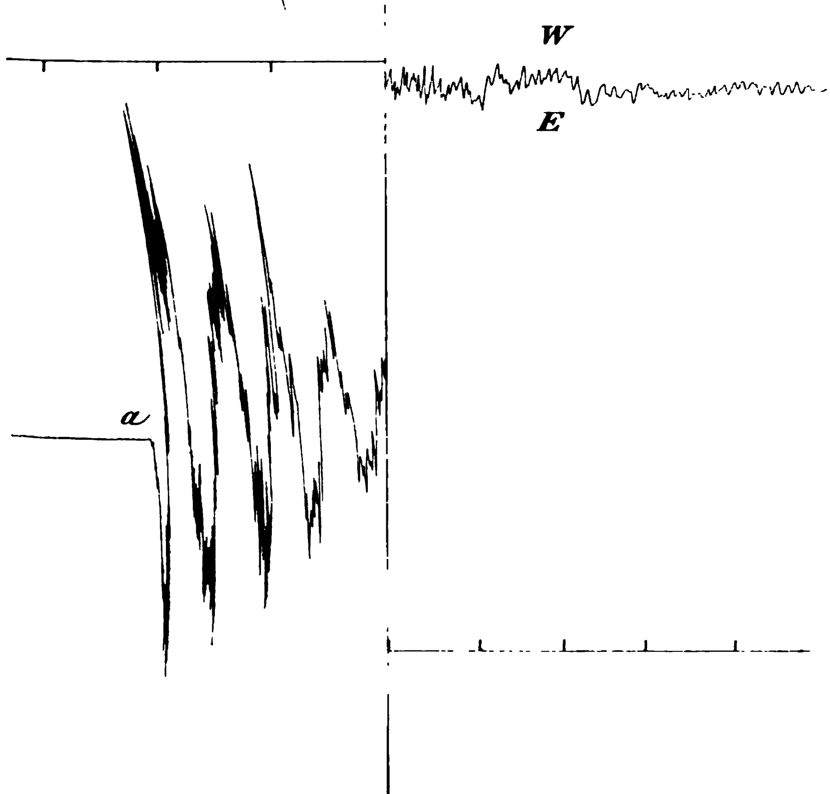
Diagrams

v. 22, 1907.

Time : 1 interval=1 min.
(*a*)......Commencement.

5. Hitotsubashi (Tokyo);
EW Component.

Multiplication=10.
Pendulum Period=26 sec.



Horizontal Pendulum Record obtained at Mito during a Storm.

By

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With Pls. VII to IX.

Instances of remarkable inclination of the ground observed in Tokyo during a storm have been described in the *Publications*, No. 21, and the *Bulletin*, Vol. I, No. 4. The present note gives an account of a similar case of the tilting recorded on March 23, 1907, at the meteorological observatory of Mito ($\varphi=36°23'$ N ; $\lambda=140°28'$ E), with the NS component Omori horizontal pendulum, whose recording cylinder made one revolution in 24 hours, and whose instrumental constants were as follows :—

Pendulum period, when suspended vertically $=T_0=1.74$ sec.
Period of Horizontal Pendulum actually set up $=T=32$ sec.
Multiplication ratio of the pointer $=n=20$.
Displacement* of the writing index corresponding to the tilting of $1''$

$$=r=L\times n\times \sin 1''\times \frac{T^2}{T_0^2}=24.57 \text{ mm.}$$

Fig. 1. (Pl. VII) gives the tiltometer record in question between 10 a.m. and 5 p.m., on the 23rd.

* In the "Bulletin," No. 4, r has by mistake been defined as the angle of tilting equivalent to 1 mm displacement of the writing index.

Storms on 22-24, March, 1907. From Fig. 2 (Pl. VIII)*, which shows the condition of the weather at 6 a.m. on March 23rd, 1907, it will be observed that there existed simultaneously two cyclones, (I) and (II), whose tracks were parallel to the general course of the Islands, and were over the Pacific Ocean and the Japan Sea respectively. The cyclone (I) appeared on the 21st off the south-eastern coast of Formosa, progressed toward north-east, and approached the south-eastern coast of the Main Island about the noon of the 23rd. The other cyclone, (II), which originated on the 20th at the Yantzse Valley, China, passed through the Tsushima Strait and approached on the 24th the western coast of Hokkaido. Both of these cyclones, which were at first shallow, rapidly increased in intensity with their eastward movement, the storm already extending over the whole of the Main Island on the afternoon of the 22nd. When the centre of the depression (I) approached on the 23rd the peninsula of Awa and Kazusa, the minimum barometric pressure of 744 mm was recorded at Choshi ($\varphi=35°44'$ N, $\lambda=140°55'$ E) at 1 p.m. The minimum pressure at Mito was 745.8 mm at 1 p.m. On the Japan Sea side, the minimum pressure, due to the cyclone (II), was 749.9 mm and was observed at Suttsu (province of Iburi, Hokkaido), at 9 p.m., on the 23rd.

Tilting of the ground. A marked southward inclination began to set in about 0h 30m p.m.; the displacement of the recording index of the instrument in that direction being 92 mm on record, which corresponds to a level inclination of 3.7″. This tilting was accomplished in the time interval of about 1h 50m, the extreme southward inclination having been reached at 2h 20m

* The weather map is reproduced from the March (1907) number of the "Kisho Yoran," published by the Central Meteorological Observatory.

p.m. Thereafter the northward inclination began to set in.

Thus it will be observed that the commencement of the sudden southward tilting was at about 30 min. before the epoch of the minimum barometric pressure at Choshi and Mito; the passage of the centre of cyclone producing, as in the case of the storm on Oct. 10th and 11th, 1904, not an elevation but the depression of the ground. This is probably due to the fact that the deep barometric cyclone was accompanied, or rather followed, by an increase of the height of sea water, to an amount greater than the equivalent of the barometric fall, as explained in the next §.

Mareogram at Choshi. Fig. 3 (Pl. IX) is a reproduction of the tide gauge diagram obtained on March 22nd and 23rd, 1907, at Choshi (province of Shimosa), which place is situated at the month of the River Tone, near Cape Inuboe, at a distance of about 80 km to the SES of Mito*. The disturbances of the water, consisting in the secondary undulations proper to the coast of observation began to become marked from about 4½ a.m. on the 23rd, continuing to increase till midnight of the same day. The level of the sea also began to rise, the greatest limit being reached at about 2 p.m. to a few minutes after 3 p.m., when the water thus abnormally accumulated was about 2½ *shaku* (=75.8 cm) higher than the level according to the usual tide movement, and 1.12 *shaku* (=34.0 cm) than the highest water during the preceding day. The time of the greatest water accumulation at Choshi thus nearly coincided with the moment of the maximum southward tilting at Mito. The difference of the highest mean level at about 3 p.m. (23rd) over that of the

* For the copy of the mareogram I am indebted to Prof. Dr. T. Kondo of the Interior Department.

mean low water occurring about 3 honrs earlier is some 1.45 *shaku* (=44 cm), which may be taken as the differential increase of the height of the sea level near the position of the cyclone over that in the neighbouring portions of the ocean. As the difference of the barometric pressure at the minimum centre and the coast near it was probably about 10 mm, or about 14 cm of water column, we see that the resultant relative pressure at the ocean bottom immediately after the passage of the cyclone centre is increased by an accumulation of water nearly 30 cm in height, extended over the sea surface of no insignificant dimension. This probably accounts for the tilting of the ground toward the centre of barometric depression, when the path of the latter is over the Pacific.

PL. VII.

Fig. 1. Omori Horizontal Pendulum (Tiltometer) Diagram.
Mito, March 23, 1907. Pendulum Period=32 sec.

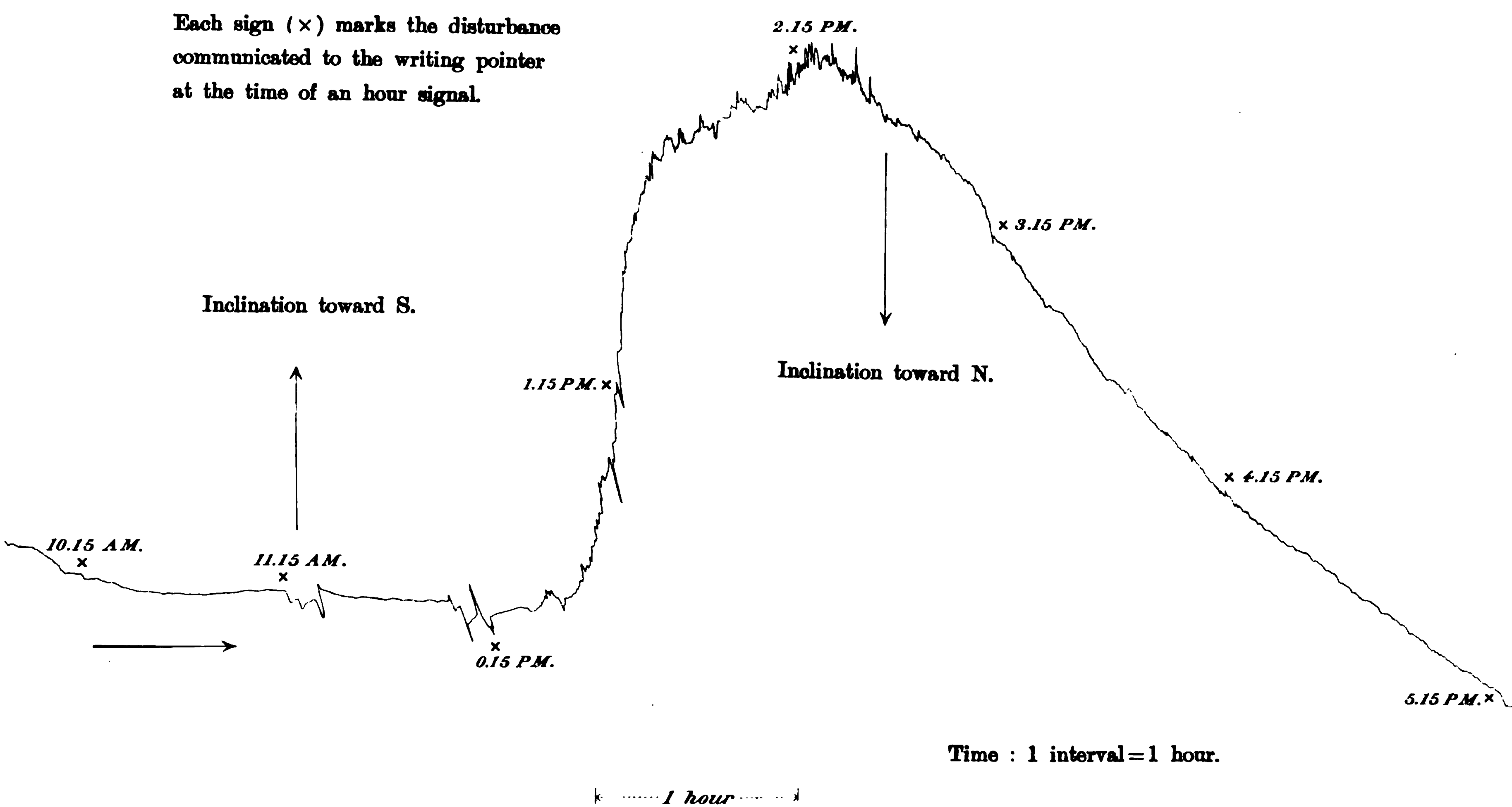
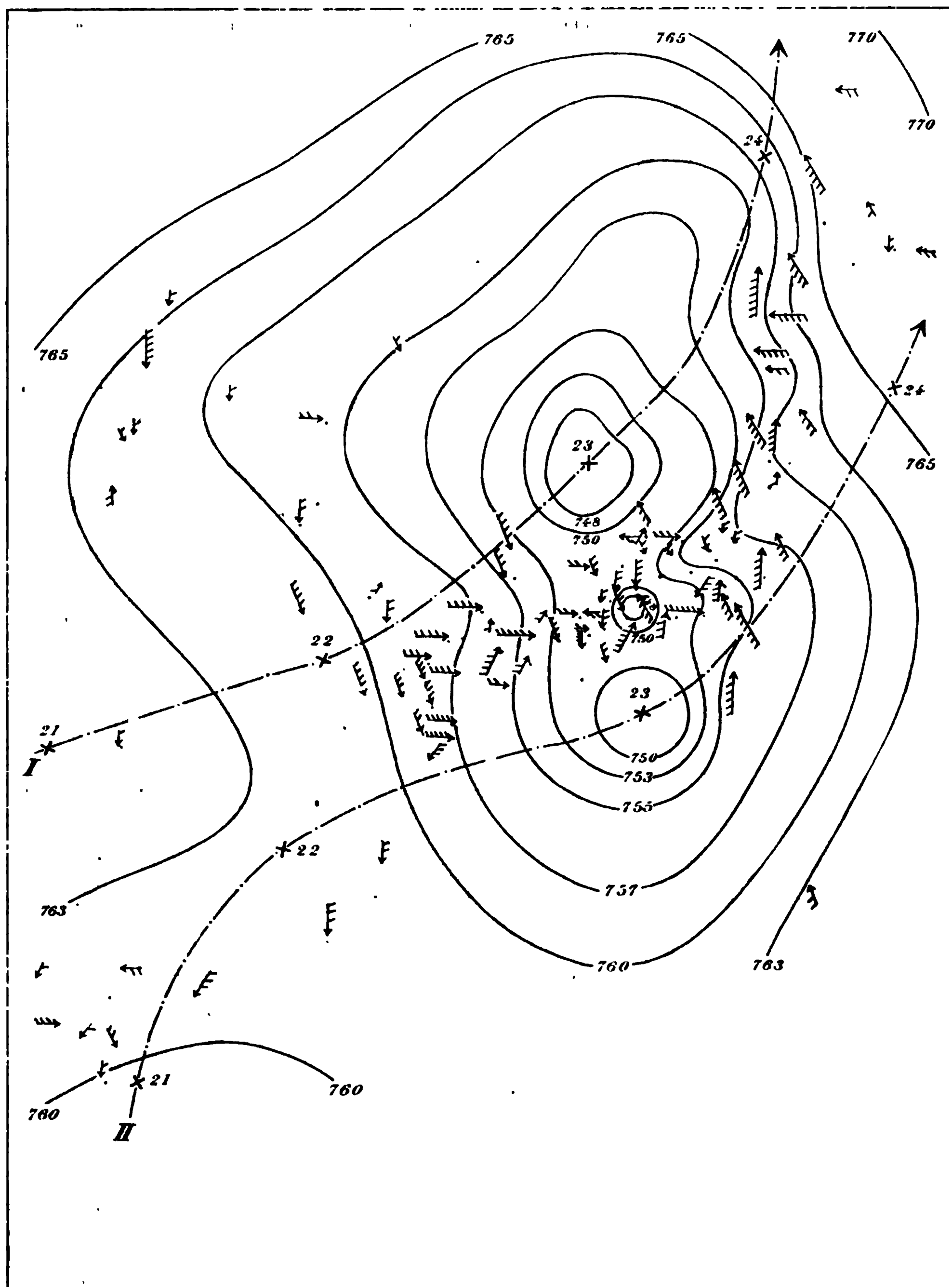


Fig. 2. Weather Map. March 23, 1907; 6 A.M.

The dotted lines (I) and (II) give the paths of the two cyclone centres, whose positions at 6 A.M. of the successive days are each indicated by a small cross (×).



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PL. IX.

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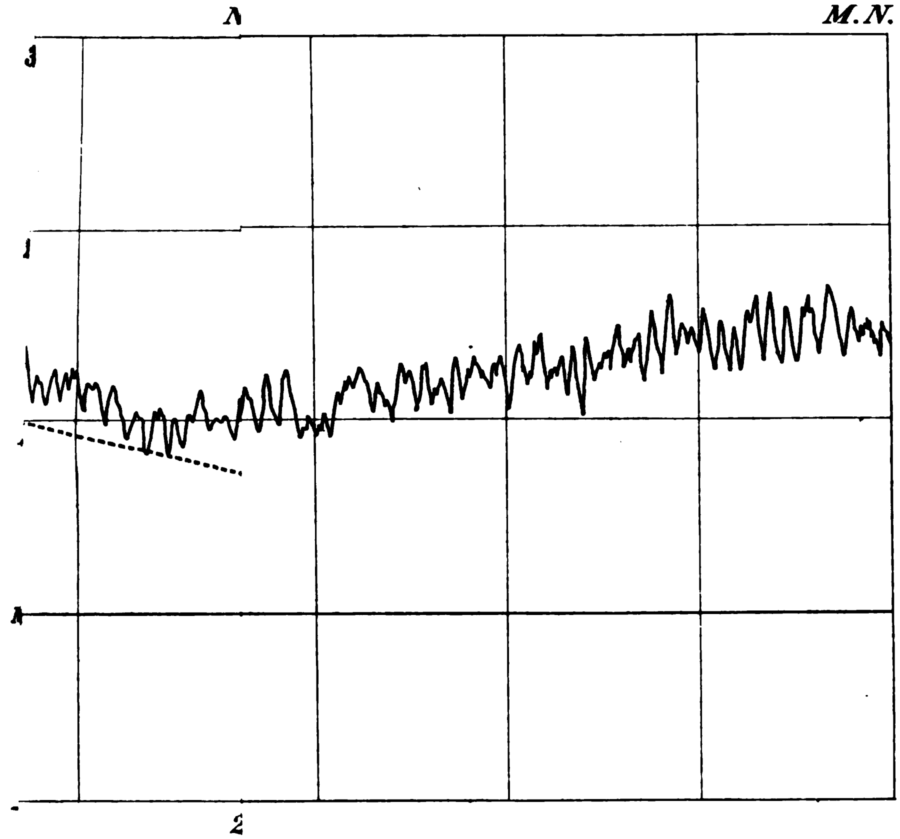

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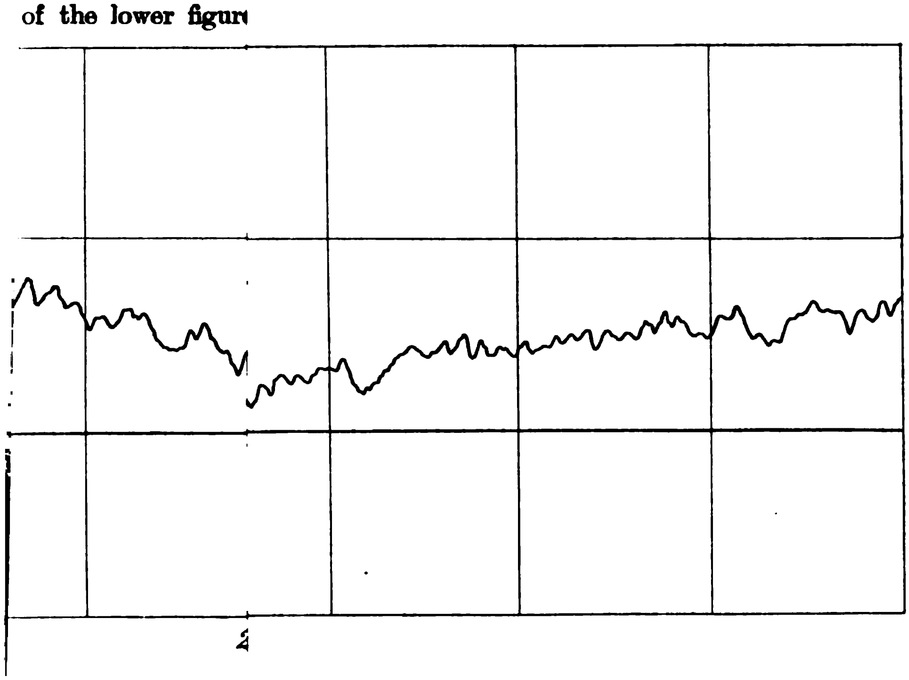

Note on the Annual Variation of Seismic Frequency in Tokyo and Kyoto.

By

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With Pl. X.

Introductory. As pointed out in a discussion of the seismic activity for Japan, taken as a whole, the variation of the frequency of the ordinary small shocks, whose number is minimum in the months of June, July, August, and September, is just the reverse of that of the destructive disturbances, whose number is maximum in July and August*. Again, with respect to the recent Japan earthquakes of submarine origin, the annual variation of the small shocks is found to be approximately opposite to that of the stronger or larger ones ‡. Relations like these between small and large seismic disturbances are what is to be expected from the nature of an earthquake, which is virtually equivalent to the removal of a weak point in the earth's crust; the more frequent occurrence of small shocks tending to prevent any abnormal accumulation of the underground stress. The non-occurrence of these disturbances, or, an unusually low seismic frequency may, on the other hand, facilitate the occurrence

* F. Omori: "Note on the Earthquake Investigation Committee Catalogue of Japanese Earthquakes." Jour. Sc. Coll., Imp. Tokyo Univ., Vol. XI, 1899.

‡ This number, Pl. XIX.

of great or destructive seismic disturbances. The reversal of the maximum and minimum epochs in the annual variation of large and small seismic shocks is also strikingly shown in the cases of the earthquakes recorded in Tokyo and Kyoto.

Seasonal variation of seismic frequency in Tokyo. The number of destructive and semi-destructive earthquakes, which shook Tokyo (Yedo) since the foundation of the city in 1590 by Tokugawa Iyeyasu, was 18, the first and last of which took place in 1615 and 1894 respectively. Of these, the maximum seasonal number of 7 occurred in Summer, while the minimum number of 3 occurred in Winter and Spring. On the contrary, the mean seasonal number of ordinary small earthquakes, observed instrumentally in Tokyo between 1876 and 1899, was minimum (=19.1 and 18.3) in Summer and Autumn, and maximum (=25.5) in Spring*, as shown in the following table.

Seasonal Seismic Frequency in Tokyo.

Season.	Mean seasonal number of ordinary eqkes. (1876–1899).	Number of destructive and semi-destructive eqkes. (1615–1894).
Spring (March, April, May).	25.5	3
Summer (June, July, August).	19.1	7
Autumn (Sept., Oct., Nov.)	18.3	5
Winter (Dec., Jan., Feb.)	23.9	3

As is graphically shown in Figs. 1 and 2 (Pl. X), the annual variation of the small earthquakes is almost symmetrically opposite to that of the destructive and semi-destructive shocks.

Annual variation of seismic frequency in Kyoto. Of the seismic disturbances recorded in Kyoto between 797, the year

* See the *Publications*, No. 8.

of its foundation, and 1867, when it ceased to be the Imperial capital, 1088 earthquakes were small shocks, and 32 were destructive or semi-destructive in or about the city*. The distribution in the 12 months of the year of these two classes of Kyoto earthquakes are as follows.

Monthly Seismic Frequency in Kyoto. (797–1867).

Month.	Ordinary small eqkes. (1088 shocks.)	Destructive and semi-destructive eqkes. (32 shocks.)
January.	79	3
February.	82	0
March.	110	0
April.	102	0
May.	95	3
June.	91	4
July.	87	5
August.	95	7
September.	74	3
October.	87	2
November.	95	1
December.	91	4

Thus the small earthquakes indicate the maximum monthly number of 110 in March, and the minimum of 74 in September; while the larger ones show the minimum number of zero in February to April, and the maximum number of 7 in August. As will also be seen from the graphical illustrations in Figs. 3 and 4 (Pl. X),

* These numbers are revised results and differ slightly from those given in Jour. Sc. Coll., Imp. Tokyo Univ., Vol. XI.

the annual variations of the two sets of earthquakes are nearly opposite to one another.

Concluding remark. From the foregoing §§, it is evident that we must treat small and large earthquakes separately, in the discussion of seismic frequency with respect to the atmospheric pressure, the position of the moon, etc.

Annual Variation of Tokyo Eqke Frequency.

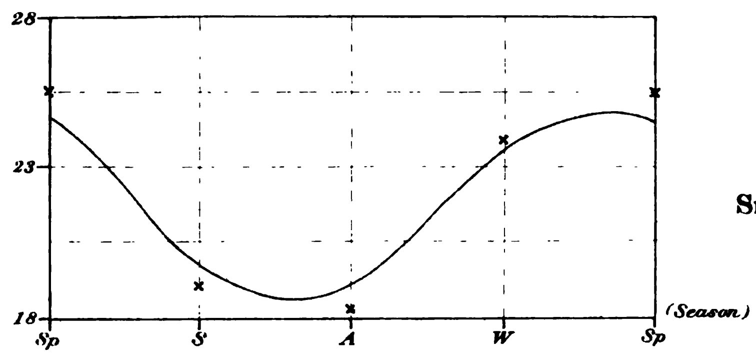


Fig. 1.
Small Eqkes.

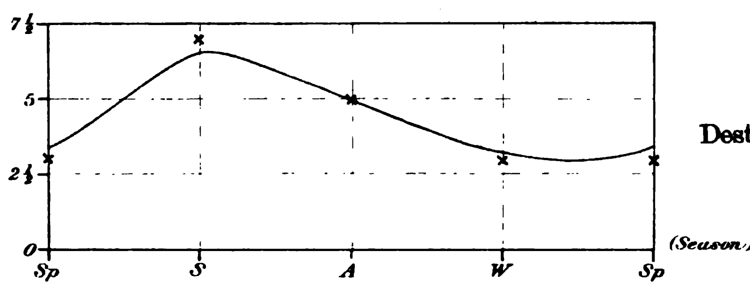


Fig. 2.
Destructive Eqkes.

Annual Variation of Kyoto Eqke Frequency.

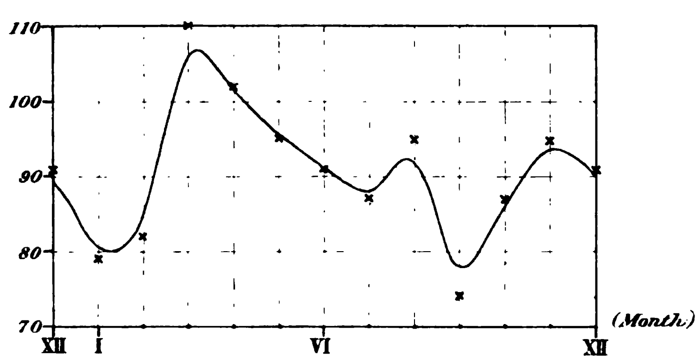


Fig. 3.
Small Eqkes.

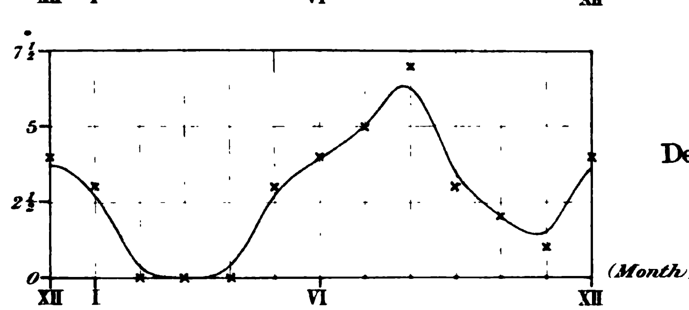


Fig. 4.
Destructive Eqkes.

List of Recent Volcanic Eruptions in Japan*.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XI-XIII.

Larger volcanic outbursts in recent years. Among the recent volcanic explosions in Japan, the most notable were the following five :—

(i) Explosion of Bandai-san. July 15, 1888; 7h 45m a.m.
(ii) „ Azuma-san (Issaikyo-san). May 19, 1893; 11h 30m a.m.
(iii) „ Adatara-san (Numashiri-yama). July 17, 1900; 6h 30m p.m.
(iv) „ Tori-shima. August, probably between the night of 7th and that of 9th, 1902.
(v) Submarine eruption near the Minami Iwo-jima (South Sulpher Island). About the 5th of December, 1904.

Of these, the first four consisted each of a sudden steam explosion, the most violent being that of the Bandai-san, one of whose peaks was entirely destroyed. The three explosions of the Azuma-san, Adatara-san, and Tori-shima were much smaller, that of the first named mountain being probably the least. A rough idea of the comparative strengths of the explosions may be obtained from

* Translation, with additions, of the present author's paper in the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 49, 1904.

the masses blown off on the different occasions*, which were approximately in the ratios of 3400 : 1 : 7 : 56, as follows :—

	(volume of newly formed crater.)	
Bandai-san	1,700,000,000	cubic metres.
Azuma-san............	500,000	„
Adatara-san	3,600,000	„
Tori-shima............	28,000,000	„

Each of these four volcanic explosions caused a considerable damage, attended by loss of human lives, which was specially striking in the case of the Tori-shima, the total population of the island, abaut 125 in number, having been entirely wiped away without leaving even a trace.

The explosion of the Adatara-san was central, that is to say, took place from the filled up crater of the original volcano, while those of the Bandai-san, Azuma-san, and Tori-shima, were each an eccentric outburst, having occurred not in the original central crater.

The submarine volcanic outburst, (v), which took place near the Minami Iwo-jima, was very remarkable and consisted in the eruption of molten lava, resulting in the formation of a new island, about 145 metres in height and nearly 5 km in circumference. This island, made up of the loose material, again entirely disappeared about I year later.

Of the 5 cases of larger volcanic outbursts mentioned above, the first three occurred in the province of Iwashiro, in the northern part of the Main Island, while the two last occurred in the Pacific and belonged to the Fuji volcanic chain.

* The estimation of the volume of newly opened crater of the Bandai-san was made by the late Professors S. Sekiya and Y. Kikuchi. Those relating to the three other volcanoes are based on the observations of the present author.

List of volcanic outbursts, 1893-1907. During the 14 years between 1893 and 1907, there were in Japan (Kuriles, Lyu-Kyu, and Formosa excepted) over 70 cases of volcanic outbursts, which consisted mostly in the explosions of steam; the mountains most active during this period being the following four :—

Asama-yama (province of Shinano)......	about 31	times
Kirishima-yama (province of Hyuga)	„ 19	„
Aso-san (province of Higo)..............	„ 6	„
Shirane-san (province of Kotsuke)	„ 5	„

Besides these, Azuma-san (Issaikyo-san), Adatara-san (Numashiri-yama), Tarumae-san (in Hokkaido), Komaga-take (Do.), Katta-dake (province of Rikuzen), and others were also more or less active; there being also two cases of submarine eruptions off the Pacific coast. The approximate positions of these volcanoes, 14 in number, are as follows.

Volcano.	Latitude (N)	Longitude (E)
Komaga-take.	42° 04′	140° 41′
Tarumae-san.	42 42	141 23
Katta-dake.	38 08	140 27
Azuma-san.	37 44	140 15
Adatara-san.	37 38	140 16
Bandai-san.	37 37	140 04
Shirane-san.	36 38	138 33
Asama-yama.	36 25	138 30
Iwo-dake.	36 15	137 36
Aso-san.	32 54	131 05
Kirishima-yama.	31 56	130 52

Volcano	Latitude (N)	Longitude (E)
Near Bayonnise Rock.	31° 55′	139° 54′
Tori-shima.	30 27	140 07
Eruption near Minami-Iwo-shima.	24 13	141 29

As a strong volcanic eruption has usually a number of smaller followers, it is often difficult to count the exact number of the outbursts. These small secondary ones have, in so far as they can be identified as such, been excluded from the following list of the volcanic disturbances.

Table I. List of Volcanic Outbursts in Japan, 1893–1907.

Volcano.	Date.	Time of Outburst.	Remarks.
	1894		
Kirishima-yama.	Feb. 25	10^h 30^m A.M.	Detonations. Ashes thrown out.
"	" 28	8 20 "	Loud detonations.
Aso-san.	March 7	5 — "	Detonations. Ashes thrown out.
	Rumbling sounds also heard at 7.13; 8.46; 9.15; 9.23; 9.40; 10.02 and 10.25 A.M. of the same day, the last being the strongest.		
"	" 13	10 40 A.M.	Detonations and explosion.
Azuma-san (Issaikyo-san).	" 16	——	Detonations. Ashes thrown out.
"	April 4	Noon.	" "
Asama-yama.	" 6	1 — A.M.	" "
"	" 11	9 — P.M.	Loud detonations. Ashes thrown out.
Azuma-san.	" 12	10 — A.M.	Ashes thrown out.
Asama-yama.	" 17	8 — A.M.	Detonations. Ashes thrown out.
"	" 28	6 20 P.M.	Outburst.
"	" 30	0 — A.M.	Loud Detonations. Ashes thrown out

Volcano.	Date.	Time of Outburst.	REMARKS.
Aso-san.	May 24	Midnight.	Detonations. Ashes thrown out.
Asama-yama.	June 14	9^h 30^m A.M.	Loud detonations. Ashes thrown out in large quantity.
Aso-san.	" 23	8 — P.M.	Loud detonations. Ashes thrown out.
Tarumae-san.	Aug. 17	6 — P.M.	Smoke emitted.
Aso-san.	" 30	5 — A.M.	Detonations.
	1895		
Katta-dake.	Feb. 15	9 — A.M.	Smoke emitted.
"	" 19	8 30 A.M.	"
Azuma-san (Issaikyo-san).	March 8	7 32 A.M.	Detonations and emission of smoke.
"	" "	9 40 P.M.	" "
Kirishima-yama.	July 16	0 30 P.M.	" "
Kumaga-take (Katta-dake).	Sept. 27	5 — A.M.	" "
Kirishima-yama.	Oct. 16	0 30 P.M.	" "
"	Dec. 18	3 45 P.M.	Loud detonations and emission of smoke.
	1896		
Kirishima-yama.	March 15	8 26 A.M.	Explosion, accompanied by emission of smoke and falling of ashes.
"	June 26	1 — A.M.	Detonations and emission of smoke. Ashes thrown out.
"	Dec. 21	1 15 P.M.	Explosion. Ashes thrown out.
	1897		
Zo-O-san (Katta-dake)	Jan. 14	0 30 A.M.	Detonations. Smoke emitted.
Aso-san.	End of Feb. to the beginning of March.	——	Detonations continued for several days, being strongest on March 3.
Shirane-san.	July 31	5 — A.M.	Detonations and emission of smoke.
Kirishima-yama.	Sept. 4	8 — A.M.	Explosion.

Volcano.	Date.		Time of Outburst.	Remarks.
	1898			
Kirishima-yama.	Feb.	8	1^h —^{m} A.M.	Detonations and emission of smoke.
"	March	11	7 — P.M.	Loud detonations and explosion.
"	Dec.	30	11 — P.M.	" " "
	1899			
Asama-yama.	March	10	1 — P.M.	Detonations and explosion.
"	July	10	Night	Explosions, continuing for several days.
"	"	15	11 — A.M.	Loud detonations and explosion.
Kirishima-yama.	"	28	1 30 A.M.	" " "
Asama-yama.	Aug.	7	7 — P.M.	" " " Ashes fell for several days.
Adatara-san.	"	24	11 30 P.M.	Explosion.
Kirishima-yama.	Sept.	12	Morning	Detonations and explosion.
"	Oct.	13	3 05 A.M.	" "
"	Nov.	7	Morning	" "
Adatara-san.	"	12	7 30 P.M.	Explosion.
	1900			
Adatara-san.	Jan.	22	7 — A.M.	Detonations and explosion.
"	Feb.	7	6 — P.M.	" "
Kirishima-yama.	"	16	9 — A.M.	" "
Asama-yama.	"	19	5 — P.M.	Loud detonations and explosion.
"	March	1	From morning to noon.	" " "
"	"	22	Midnight	Detonations, followed by several others.
"	"	31	3 10 P.M.	Loud detonations and explosion.
Adatara-san.	July	17	6 30 P.M.	Great explosion. (See the 1st §)
Asama-yama.	"	21	—	Explosion.
Shirane-san.	Oct.	1	3 — A.M.	Feable detonations and explosion.
Asama-yama.	Nov.	19	4 30 P.M.	Explosion.

Volcano.	Date.	Time of Outburst.	Remarks.
Asama-yama.	Dec. 14	4^h —^{m} A.M.	Feeble shaking and explosion.
	1901		
Asama-yama.	April 20	0 25–5 00 P.M.	Explosion.
"	" 21	10 30 A.M.	Emission of smoke.
"	May 25	10 50 A.M.	" "
"	" 26	2 00 P.M.	" "
"	July 21	Evening	Explosions continued for several days.
"	Aug. 6–8	—	" " (Ashes fell also on 9th and 10th.)
	1902		
Asama-yama.	Aug. 5	1 — P.M.	Detonations. Ashes thrown out.
Tori-shima.	Aug. (probably between evening of 7th and that of 9th)		Great explosion. (See the 1st §)
Shirane-san.	Sept. 5	Evening	Small explosion.
"	" 17	1 — P.M.	" "
	1903		
Kirishima-yama.	Aug. 29	2 30 P.M.	Detonations and explosion.
"	Nov. 25	9 — A.M.	Great detonations and explosion.
	1904		
Asama-yama.	Aug. 4	Noon	Smoke emitted, and ashes thrown out.
Near the Minami Iwo-jima.	(About Nov. 28)	——	A great submarine eruption, resulting in the formation of a new island.
	1905		
Komaga-take.	Aug. 20	11 — P.M.	Explosion. Ashes continued to be thrown out till the end of the year.
Shirane-san.	Oct. 24(?)	——	Smoke emitted, and ashes thrown out.
	1906		
Asama-yama.	April 6	Early morning	Smoke emitted.
In the vicinity of Bayonnaise Rock, to the SE of Aogashima.	April (probably between 7 and 13)	——	A submarine eruption, which continued probably for about one week. A great quantity of pumice was found floating on the sea surface.

Volcano.	Date.	Time of Outburst.	Remarks.
Aso-san.	June 8	5^h — P.M.	Detonations, followed by an explosion. A new crater, about 50 ft in length and 24 ft in width was formed.
	1907		
Asama-yama.	Jan. 18	Continued from the evening of 18th to the morning of 19th	Smoke emitted.
"	March 28	6 — A.M.	Smoke emitted, and ashes thrown out.
"	Aug. 24	Early morning	" "
Iwo-dake. (in Shinano)	Dec. 11	——	Explosion. Ashes were thrown out.

Annual variation of the frequency of the volcanic outbursts. The distribution in the 12 months of the year of the 80 cases of volcanic disturbances contained in the list given in the preceding § is shown in the 2nd column of the following table; the figures in the 3rd column, taken from the late Mr. Ogashima's work, "Nippon Saiishi," (*A compendium of unusual events in Japan*), being the annual distribution of the 113 volcanic outbursts, which happened in Japan since the earliest historical times down to 1885*.

Table II. Volcanic Eruptions in Japan.

Month.	80 Vol. Outbrusts in recent years. 1893-1907	113 Vol. Outbursts recorded in history. 685-1886	*Sum.* (193 Outbursts).
I	3	6	**9**
II	9	20	**29**
III	12	13	**25**

* For accounts of historical volcanic outbursts in Japan, the reader is also referred to Prof. John Milne's paper, "the volcanoes of Japan," in the Trans. Seism. Soc. Japan, Vol. IX.

Month.	80 Vol. Outbursts in recent years. 1893-1907	113 Vol. Outbursts recorded in history. 685–1886	*Sum.* (193 Outbursts).
IV	11	14	**25**
V	3	8	**11**
VI	4	4	**8**
VII	8	7	**15**
VIII	11	14	**25**
IX	5	9	**14**
X	4	3	**7**
XI	5	9	**14**
XII	5	6	**11**

The annual variations of the recent volcanic outbursts and of those which occurred in the historical times are, as illustrated in Figs. 1 and 2 (Pl. XI), mutually alike, each showing two distinct maxima of the frequency. The monthly distribution of the two sets of eruptions taken together is given in the last column of the above table and illustrated in Fig. 3. From the latter it will be seen that the absolutely greatest frequency (29) of eruptions occurred in February; the three months of February, March, and April together forming the 1st, or principal epoch of volcanic activity, followed by the principal minimum in June. The 2nd, or smaller, maximum frequency (25) occurred in August.

Comparison with the annual variation of seismic frequency. To compare the annual variation of the frequency of the volcanic eruptions with that of the seismic frequency, I give, in Table III, the mean monthly percentage numbers of earthquakes observed instrumentally at the meteorological observatories of

Nagoya, Gifu, and Kumamoto, which places are shaken mostly by seismic disturbances of inland origin; the figures having been deduced from the data given in the "Publications of the Imp. Earthquake Inv. Comm.", No. 8.

Table III. Mean Monthly Percentage Numbers of Earthquakes at Nagoya, Gifu, and Kumamoto.

Month.	Nagoya.	Gifu.	Kumamoto.	*Average.*
I	13.3	10.7	10.9	**11.6**
II	7.5	8.2	9.3	**8.3**
III	13.0	9.9	9.9	**10.9**
IV	9.6	13.9	9.5	**11.0**
V	9.0	9.2	10.5	**9.6**
VI	6.3	6.9	9.6	**7.6**
VII	6.0	6.0	4.9	**5.6**
VIII	11.2	5.5	7.5	**8.1**
IX	6.6	6.5	7.5	**6.9**
X	6.9	8.2	8.8	**8.0**
XI	4.8	8.6	6.1	**6.5**
XII	5.8	6.5	5.5	**5.9**

According to the average values of the monthly seismic frequency, which are given in the last column of Table III, and which are graphically illustrated in Fig. 4, the annual variation of the frequency of the earthquakes of inland origin shows the epoch of the principal maximum (=11) in March and April, with the principal minimum (=5.6) in July; there being an epoch of a secondary maximum (=8) in the months of August to October. The variation in question may thus be regarded as

being on the whole approximately similar to that of the frequency of the volcanic eruptions.

With respect to the cause of the frequency variations of these two phenomena, it is to be remarked that the earthquakes of inland origin are much affected by the atmospheric pressure, as discussed in the *Publications*, No. 8; the 1st, or principal, seismic maximum above mentioned being due probably to the barometric maximum in the annual variation. The 2nd, or smaller, seismic maximum may possibly be due to the more extensive or stronger among the earthquakes of inland origin taken into consideration; the annual variation of large and small shocks being in general opposite to one another. The cause for the two maxima in the frequency variation of the volcanic eruptions is probably the same as in the case of those of the earthquakes. It is needless to add that further and more strict investigations in these connections are necessary, especially for the explanation of the secondary maximum in the frequency of volcanic eruptions*.

Seasonal numbers of volcanic eruptions. The following table gives the distribution in the four seasons of the year of the 193 volcanic eruptions (Table II) and of the percentage numbers of the earthquakes observed at Nagoya, Gifu, and Kumamoto based on the data given in Table III.

* In the Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 56, I have stated the view that the secondary maximum in the frequency of the volcanic eruptions may be due to the pressure ot the sea water at the bottom. The supposition stated in the present paragraph seems to be the more likely one.

Table IV. Seasonal Distribution of the Volcanic Eruptions and the Percentage Numbers of the Earthquakes.

Season.	Volcanic Eruptions. (193)	Seismic Frequency.			
		Nagoya.	Gifu.	Kumamoto.	*Mean.*
Spring (March, April, May.)	61	31.6	33.0	30.3	31.6
Summer (June, July, August.)	48	23.5	18.4	22.3	21.4
Autumn (Sept., Oct., Nov.)	35	18.4	23.2	22.7	21.4
Winter (Dec., Jan., Feb.)	49	26.5	25.4	24.7	25.5

Thus, for the volcanic eruptions, the greatest seasonal number of 61 occurred in Spring, being 1.7 times greater than the least number, which occurred in Autumn. For the mean frequency of the earthquakes, the greatest percentage number of 31.6 occurred also in Spring, being about 1.5 times greater than the least number of 21.4, which occurred in Summer and Autumn. The curves graphically representing the variations of the seasonal frequencies of the eruptions and the earthquakes, given in Figs. 5 and 6, (Pl. XII), will be seen to be on the whole similar to one another.

Numbers of volcanic eruptions in the successive years. Table V gives the number of the volcanic eruptions for each of the years 1894 to 1907, and for the sake of comparison, the total numbers of earthquakes (exclusive of teleseismic disturbances) observed in Japan during the successive years.

Table V. Yearly Numbers of Volcanic Eruptions and Earthquakes in Japan. 1894–1907.

Year.	Number of Volcanic Eruptions.	Number of Earthquakes*.
1894	17	2,729
1895	8	1,417
1896	3	1,906
1897	4	1,727
1898	3	1,561
1899	10	1,682
1900	12	1,831
1901	6	1,615
1902	4	1,401
1903	2	1,242
1904	2	1,142
1905	2	1,901
1906	3	1,551
1907	4	1,642

(* Formosa excluded)

From Figs. 7 and 8 (Pl. XIII), which graphically illustrate the results contained in Table V, it will be seen that the relations to time of the numbers of the eruptions and the earthquakes are rather alike to each other; in each case the absolutely greatest number occurring in 1894, and a maximum in 1900.

From what has been said in the foregoing §§, the volcanic activity in Japan seems to follow approximately that of earthquakes. This is in accordance with the fact that large volcanic eruptions and destructive earthquakes often take place in nearly the same epoch in different parts of a great seismic zone.

Annual Variation of the Volcanic Eruptions and Earthquakes in Japan.

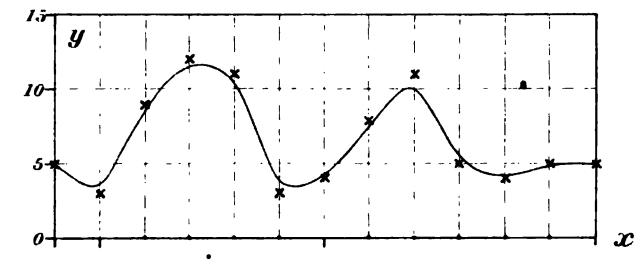


Fig. 1. 80 recent Volcanic Eruptions.

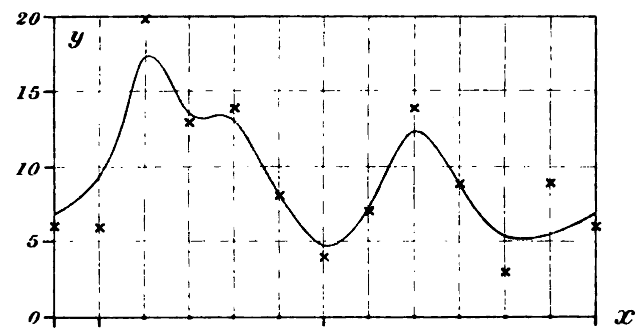


Fig. 2. 113 historical Volcanic Eruptions.

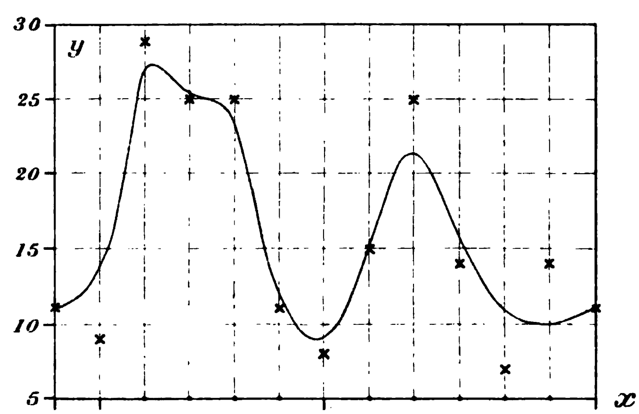


Fig. 3. 193 recent and historical Volcanic Eruptions.

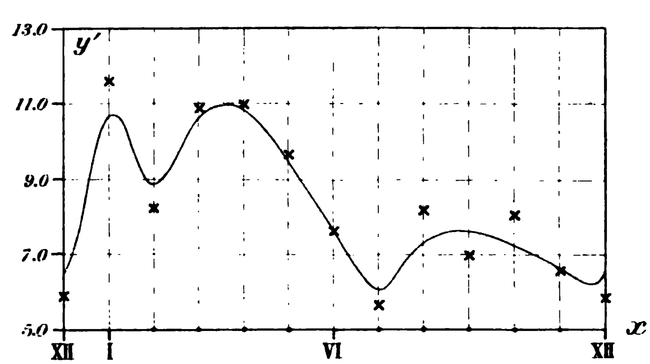


Fig. 4. Earthquakes of Inland Origin.

x = Time, in months.
y = Monthly number of volcanic eruptions in Japan.
y' = Mean monthly percentage number of earthquakes of inland origin.

Seasonal Distributions of the Volcanic Eruptions and Earthquakes in Japan.

Fig. 5. 193 Volcanic Eruptions.

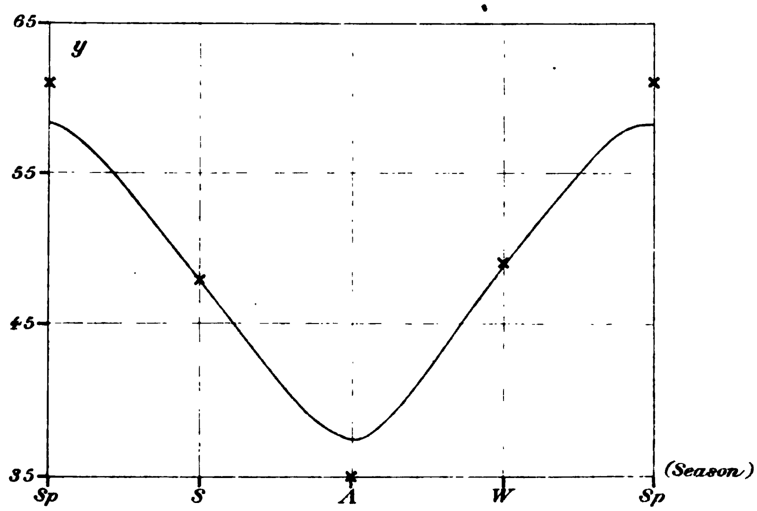
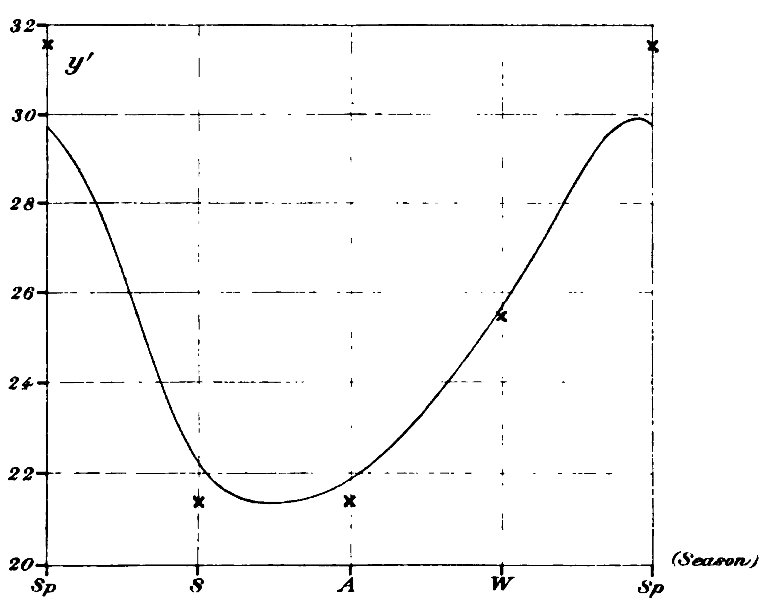


Fig. 6. Earthquakes of Inland Origin.



y = Monthly number of volcanic eruptions in Japan.
y' = Mean monthly percentage number of earthquakes of inland origin.

Variations of the Yearly Numbers of the Volcanic Eruptions and Earthquakes in Japan.

Fig. 7. Volcanic Eruptions.

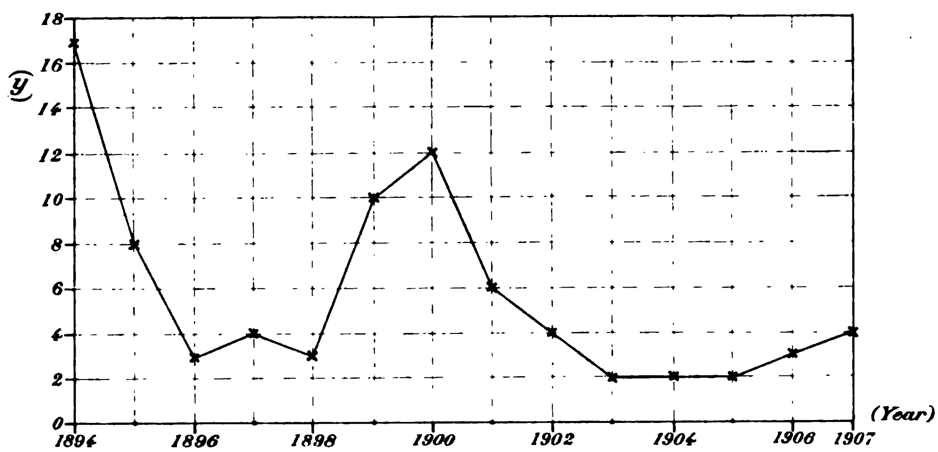
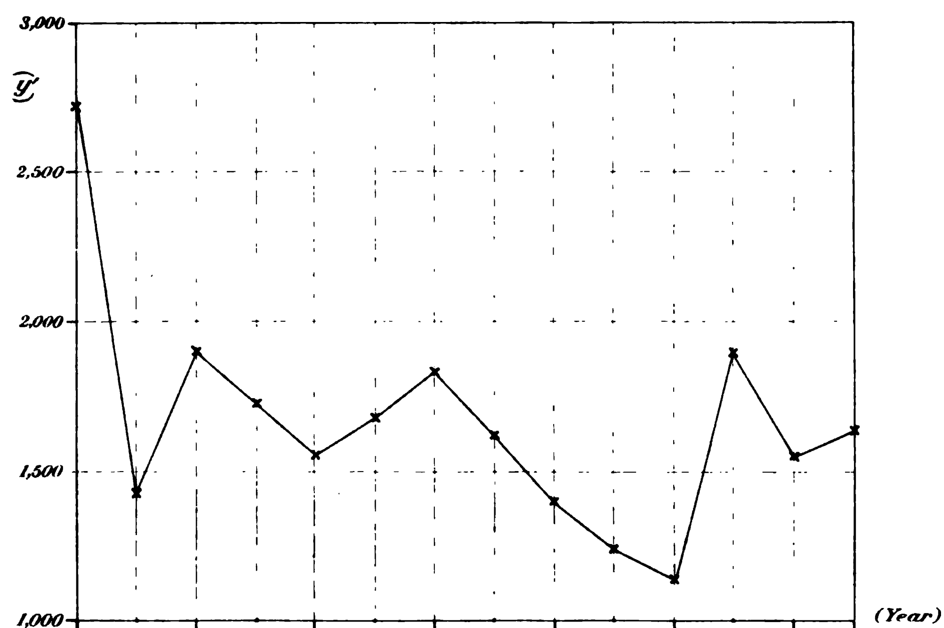


Fig. 8. Earthquakes.



y = Yearly number of volcanic eruptions in Japan.
y' = „ „ „ earthquakes in Japan (Formosa excepted).

On the Annual Variation of the Height of Sea-Level along Japanese Coasts. *2nd Paper.*

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XIV-XIX.

Introductory. In a previous note* I have considered the relation to the barometric pressure and the seismic frequency of the annual variation during 1902 of the height of sea-level at Ayukawa and Misaki, which are situated on the Pacific coast of the Main Island. The present paper treats of the same relation for these two places during the year 1903, and also gives the discussion of the sea-level observations during 1904 made at Choshi (province of Shimosa) on the Pacific side, and at the four Japan-Sea coast stations of Otaru, Iwasaki, Wajima and Hamada. The data relating to the mean monthly heights of sea level at Choshi are based on the report of the meteorological observatory at that town, while those relating to all the other places have been furnished by the Survey Department of the General Staff of the Imperial Army; the tidal measurement at each place being made by means of an automatically recording mareograph. The approximate positions of the different stations, which are shown in Fig. 1 (Pl XIV), are as follows.

* The "Publications of the Earthquake Inv. Comm.", No. 18.

Stations.	Latitude (N).	Longitude (E).
Otaru.	43° 13′	141° 01′
Iwasaki.	40 36	139 55
Ayukawa.	38 18	141 31
Chōshi	35 44	140 50
Misaki.	35 10	139 37
Wajima (Wajima-zaki).	37 25	136 54
Hamada (Sotonoura).	34 55	132 05

Height of sea-level at Ayukawa and Misaki, in 1903. Table I gives the mean relative monthly heights of sea surface for 1903 at Ayukawa (province of Rikuzen) and Misaki (province of Sagami), while Table II gives the mean monthly atmospheric pressure for the same year deduced from the barometric observations at the meteorological observatories of Ishinomaki and Yokosuka, respectively near to the two mareograph stations above named.

Table I. Mean Monthly Relative Heights of Sea Level at *Ayukawa* and *Misaki*. **1903.**

Month.	Ayukawa.	Misaki.	*Mean.*
January.	131 mm	101 mm	116 mm
February.	75	60	68
March.	12	0	6
April.	0	19	10
May.	116	102	109
June.	187	185	186

Month.	Ayukawa.	Misaki.	*Mean.*
July.	257 mm	183 mm	220 mm
August	233	206	220
September.	246	190	218
October.	220	220	220
November.	166	191	179
December.	187	133	160

Table II*. Mean Monthly Barometric Heights at Ishinomaki and Yokosuka. **1903.**

Month.	Ishinomaki.	Yokosuka.	*Mean*
January.	700 mm + 62.4 mm	700 mm + 62.7 mm	700 mm + 62.6 mm
February.	62.7	63.0	62.9
March.	64.2	63.9	64.1
April.	63.3	63.1	63.2
May.	60.0	60.1	60.1
June.	56.1	55.9	56.0
July.	56.5	57.1	56.8
August.	58.8	58.9	58.9
September.	61.2	60.6	60.9
October.	63.3	62.5	62.9
November.	63.4	63.1	63.3
December.	61.3	61.8	61.6

The 2nd and 3rd columns of Table III give the relative monthly values of the heights of sea surface and of the atmos-

* Reduced to sea level and the freezing point.

pheric pressure, respectively meaned from the Ayukawa and Misaki mareograph observations (Table I) and from the Ishinomaki and Yokosuka barometric readings (Table II), the figures indicated in the 4th column being the relative total amount of pressure expressed in height of water column at the sea bottom itself, obtained by adding the aqueous and the atmospheric pressures as above deduced. From Figs. 2 and 3 (Pl. XV), it will be seen that the annual variation of the height of sea surface is on the whole opposite to that of the atmospheric pressure; the sea water being lowest in March, and the barometric height maximum in the same month. The total pressure at the sea bottom varied relatively between 110 and 308 mm, the maximum and minimum occurring respectively in Octobor and March.

Table IV gives the data for 1902, meaned from Ayukawa and Misaki, as well as the total pressure at the sea bottom averaged from the two years 1902 and 1903. As will be seen from Fig. 8, the annual variation of the latter quantity presents the maximum in October and the minimum in March and April, the amount of fluctuation being 194 mm of water column, or 14.3 mm of mercury, which is about 1½ times that of the fluctuation of the monthly mean of the barometric pressure.

Table III. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki*.** **1903.**

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom.*
	mm	mm	mm
January.	110	6.6	200
February.	62	6.9	156
March.	0	8.1	110 (min.)
April.	4	7.2	112

* Expressed in column of water.

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom*.
May.	103 mm	4.1 mm	159 mm
June.	180	0.0	180
July.	214	0.8	225
August.	214	2.9	253
September.	212	4.9	279
October.	214	6.9	308 (max.)
November.	173	7.3	272
December.	154	5·6	230

Table IV. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki***. **1902** and **1903.**

Month.	Height of Sea Level. 1902.	Barometric Pressure. 1902.	Total Pressure at Sea Bottom.* 1902.	Total Pressure at Sea Bottom.* 1902-1903 (mean.)
January.	125 mm	5.1 mm	194 mm	197 mm
February.	0	8.3	111 (min.)	134
March.	46	6.0	128	119 (min.)
April.	74	4.0	128	120 (min.)
May.	142	3.2	185	172
June.	171	0.2	174	177
July.	186	0.0	186	206
August.	205	2.6	240	247
September.	248	2.5	282	281
October.	210	7.9	317 (max.)	313 (max.)
November.	141	9.3	267	270
December.	207	4.8	272	251

* Expressed in column of water.

Comparing Figs. 2 and 3 with the figures in the 1st paper (the *Publications*, No. 18), we see that the relation of the variation of the height of sea surface to that of the atmospheric pressure remained essentially identical in the two years of 1902 and 1903, the only difference being that the epoch of the lowest water and highest barometer occurred in 1902 in February, and in 1903 in March.

In 1902, the amount of the fluctuation of the mean monthly values of the height of sea surface was 248 mm, while that of the atmospheric pressure was equivalent to 126 mm of column of water; these two numbers being in the ratio of 197 : 100. In 1903, the amount of fluctuation of the height of sea water was somewhat smaller, namely, 214 mm, that of the atmospheric pressure being also smaller and equivalent to 110 mm of water column. These two latter nnmbers are in the ratio of 195 : 100, which is nearly equal to that for 1902.

Observation at Choshi (1904)*.* The following table gives the mean monthly values of the relative height of sea surface and the atmospheric pressure at Choshi, near the Cape Inuboe, in the province of Shimosa.

Table V. Mean Monthly Height of Sea Surface and Barometric Pressure at ***Choshi. 1904.***

Month.	Height of Sea Surface.	Barometric Pressure.‡
January.	27 mm	700 mm + 62.6 mm
February.	0	63.6

* This account of the Choshi observation was also given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," Vol. I.

‡ With gravity, sea level, and freezing point corrections.

Month.	Height of Sea Surface.	Barometric Pressure.
March.	75 mm	62.1 mm
April.	27	63.4
May.	78	59.3
June.	48	57.8
July.	130	57.7
August.	190	58.5
September.	236	58.3
October.	215	61.4
November.	72	61.2
December.	33	61.9

The above figures relating to the height of sea level and the barometric pressure have been deduced from the reading at 6 a.m. each day, during the year 1904. As will be seen from the above table, which is illustrated in Figs. 4 and 5 (Pl XVI), the sea surface was highest in September and lowest in February, while the barometric pressure was highest in February and lowest in June to September; the annual variation of the two quantities being approximately the reverse of each other, as was the case with Ayukawa and Misaki.

The difference between the mean monthly maximum and minimum heights of the sea surface was 236 mm, while that of the atmospheric pressure was equivalent to 86 mm of water column; these two numbers being in the ratio of 275 : 100.

***Japan Sea coast**.** The annual variation of the height of sea surface considered in the preceding §§ relates to three places

* An account of the Japan Sea coast observations has been given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," in 1905.

on the Pacific coast of Japan. Let us now consider the same subject relative to the Japan Sea coast, there being on the latter the following four mareograph stations :—

(i) Hamada, in the province of Iwami;
(ii) Wajima, on the northern coast of the Peninsula of Noto;
(iii) Iwasaki, on the western coast of the province of Mutsu;
(iv) Otaru, in the province of Shiribeshi (Hokkaido).

Table VI gives the mean monthly values of the distance between the sea surface and the datum line in the mareogram at each of the above mentioned places; Table VII giving the mean monthly barometric pressures during the same year observed at the meteorological observatories of Hamada, Wajima, Aomori, and Sapporo. The two last cities have been chosen on account of their proximity respectively to Iwasaki and Otaru, there being no meteorological observatory at these two latter places. Finally, Table VIII gives the mean monthly values of the relative height of sea surface and of the atmospheric pressure, deduced from Tables VI and VII respectively.

Table VI. Mean Relative Monthly Position of the Sea Surface.
Japan Sea coast. 1902.

Month.	Relative distance between the sea surface and the datum line of the Mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
January.	307 mm	226 mm	180 mm	159 mm	218 mm
February.	396	330	317	278	330
March.	319	305	277	225	282

Month.	Relative distance between the sea surface and the datum line of the mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
	mm	mm	mm	mm	mm
April.	307	289	211	162	242
May.	149	154	135	119	139
June.	117	109	136	93	114
July.	83	69	112	103	92
August.	34	25	79	79	54
September.	0	0	0	70	18
October.	112	73	107	0	73
November.	206	180	170	66	156
December.	192	158	155	89	149

Table VII. Mean Monthly Barometric Pressure*.

Japan Sea coast. 1902.

Month.	Hamada.	Wajima.	Aomori.	Sapporo.
	mm	mm	mm	mm
January.	764.4	763.6	760.3	757.22
February.	66.5	66.1	63.3	60.09
March.	62.5	63.1	61.6	59.27
April.	60.6	61.2	58.4	55.20
May.	57.5	58.7	58.3	56.32
June.	54.4	56.1	56.1	62.23
July.	55.0	55.7	56.0	55.06
August.	55.8	57.4	59.0	57.78
September.	56.5	57.1	58.7	57.90
October.	63.8	64.2	64.3	62.24
November.	65.1	65.7	65.1	62.79
December.	62.5	62.2	61.1	59.66

* Reduced to the freezing point and the sea level.

Table VIII. Comparison of the Height of Sea Surface with the Barometric Pressure.

***Japan Sea coast.* 1902.**

Month.	Relative Height of Sea Surface.	Relative Barometric Pressure.	Relative Total Pressure at the Sea Bottom.
January.	112 mm	5.94 mm	193 mm
February.	0	8.76	119
March.	48	6.17	132
April.	88	3.41	134
May.	191	2.26	222
June.	206	1.77	230
July.	238	0.00	238
August.	276	2.05	304
September.	312	2.11	341
October.	257	8.20	368
November.	176	8.98	298
December.	181	5.93	262

As will be seen from Table VI, the sea-level was lowest in February, and highest in September or October. The annual amounts of fluctuation of the mean monthly height of sea-level at Hamada, Wajima, Iwasaki and Otaru were respectively 396, 330, 317, and 278 mm, decreasing from the south to the north.

From Table VIII, the annual variation of the barometric pressure will be seen, as in the case of the places on the Pacific coast, to be nearly the reverse of that of the height of sea-level. Now the amount of fluctuation of the mean monthly

barometric pressure, averaged from the observations at Hamada, Wajima, Aomori, and Sapporo, was 8.98 mm, which corresponds to $8.98 \times 13.6 = 122$ mm height of water. On the other hand, the annual fluctuation of the mean monthly height of sea-level, averaged from the observations at the four places of Hamada, Wajima, Iwasaki, and Otaru, was 312 mm. Along the Japan Sea coast, therefore, the fluctuation of the height of sea surface was opposite to, and nearly 2.6 times larger than, the corresponding fluctuation of the barometric pressure. In other words, the sea bottom is subjected to a greater total pressure in the summer months than in February, March, and April, the difference between the maximum and minimum total pressures being equal to 249 mm of water column, which is equivalent to 18.3 mm of mercury, and almost exactly twice the amount of fluctuation of the barometric pressure. The results containnd in Table VIII are illustrated in Figs. 6,7, and 9.

Comparison of the observations on the Pacific and Japan Sea coasts. According to the observations in 1902, the variations during the year of the height of sea surface and the barometric pressure on the Pacific and Japan Sea coasts were as follows :—

(A). Amount of Fluctuation of the Mean Monthly Values. **1902.**

Place.	Barometric Pressure. (mercury column)	Height of Sea Surface. (water column)	Total Pressure at Sea Bottom. (water column)
Pacific Coast. (Ayukawa and Misaki)	9.3 mm	248 mm	206 mm
Japan Sea Coast (Hamada, Wajima, Iwasaki, Otaru).	8.98	312	249

Again from the observations in 1903 and 1904, we obtain the following results.

(B). Amount of Fluctuation of the Mean Monthly Values.

Pacific Coast. **1903** and **1904.**

Place	Barometric Pressure.	Height of Sea Surface.	Total Pressure at Sea Bottom.
	(mercury column)	(water column)	(water column)
Ayukawa, Misaki.. ....1903.	8.1 mm	214 mm	198 mm
Choshi ......1904.	6.3	236	224

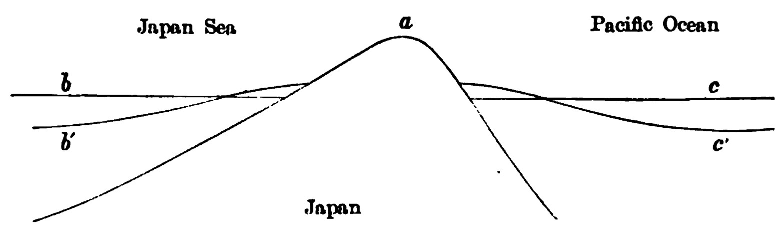
The relation between the height of sea surface and the barometric pressure, which may change from year to year depends without doubt on geograhphical features of a given coast. But. according to the two above tables, the different fluctuations were contained within fairly uniform limits, the annual variation of the height of sea surface being from 214 to 312 mm, and that of the total pressure at the sea bottom from 198 to 249 mm. There was no marked difference in these respects between the Pacific and Japan Sea coasts. Taking the simple averages from (A) and (B), we obtain the following mean values of the annual variation:—

$$\begin{cases} \text{Barometric Pressure..........8.17 mm of mercury} = \text{111 mm of water.} \\ \text{Height of Sea Surface........253 mm of water.} \\ \text{Total Pressure at Sea Bottom..219 mm of water.} \end{cases}$$

Thus the amount of fluctuation of the total pressure at the sea bottom was 219 mm, which is greater than that of the barometric

pressure in the ratio of 197 : 100, or very nearly in the ratio of 2 : 1. The sea bottom pressure is maximum in October or September, and minimum in February to April.

The increase during the summer months in the height of sea level, as above described, is to be explained, partly by the



fall in that epoch of the year of the barometric pressure over Japan and the neighbouring seas, and partly by the presence of a high pressure centre on the northern Pacific in the vicinity of the Aleutian Islands. Thus, if *b* and *c* (see the annexed diagram) represents the normal, or mean, level of the sea, the latter will be depressed to *b'* and *c'* through the influence of the high pressure area at *c*, and elevated along the coasts of Japanese Islands under the influence of the low pressure at *a*, the resulting equilibrium surface of water being a curved form, *b'* and *c'*. Similarly the decrease of the height of sea level in the winter months is to be explained by the rise of the barometric pressure over Japan and the presence of a low pressure centre on the Northern Pacific. It is probable that the co-existence of the centres of high and low barometric pressures respectively over the land and the ocean (or *vice versa*) causes, by the superposition of the effects, the amount of the annual variation of the height of sea to be approximately double that of the atmospheric pressure.

Seismic frequency and total pressure at sea bottom. To compare the annual variation of the frequency of earthquakes

of submarine origin with that of the total pressure at sea bottom, I indicate in the following table the mean monthly percentage numbers of earthquakes for Nemuro, Miyako, Ishinomaki, Kochi, and Hamada; the figures being based on the data given in the "Publications of the Earthquake Inv. Comm.", No. 8. Of these five places, each of which is disturbed mostly by earthquakes of submarine origin, the first four are situated on the Pacific coast of Japan, and the remaining one on the Japan Sea coast.

Table IX. Annual Variation of Seismic Frequency.

Month.	Nemuro.	Miyako.	Ishino-maki.	Kochi.	Hamada.	*Mean.*
January.	6.5	6.2	4.1	6.9	6.8	5.9
February,	6.5	4.4	5.7	11.7	6.8	6 5
March.	7.7	8.1	5.3	9.3	6.8	7.8
April.	7.8	10.0	8.1	9.3	3.3	8.1
May.	9.4	6.9	8.1	4.8	3.3	7.1
June.	9.4	9.0	7.5	10.5	3.3	8.2
July.	9.6	12.2	11.5	8.1	3.3	9.8
August.	8.0	12.1	13.2	6.9	13.3	10.9
September.	8.4	5.3	10.5	5.7	10.0	8.0
October.	9.4	9.7	8.4	8.1	20.0	10.4
November.	8.4	9.0	11.0	8.1	10.0	9.4
December.	8.8	6.9	6.8	10.5	13.3	8.6

The mean seismic frequency, given in the last column of the above table, has been deduced from the figures for the five different places; the weight of the data relating to Kochi and

Hamada, whose earthquake numbers were not numerous enough, being taken as half of that for the others. The annual variation of the mean seismic frequency thus obtained is illustrated in Fig. 11, while that of the relative total sea bottom pressure, deduced by taking the means of the results relating to the Pacific and Japan Sea coasts is illustrated in Fig. 10.

From a comparison of Figs. 10 and 11, it will be seen that the frequency of submarine earthquakes follows, on the whole, the variation of the total pressure at the sea bottom. Thus, the earthquake number is minimum in January and February, and maximum in August, and the sea bottom pressure is minimum in February to April, and maximum in September and October.

Stronger earthquakes of submarine origin. The seismic frequencies considered in the preceding § relate essentially to small ordinary, or non-destructive, earthquakes and may therefore, in their annual variation, be different from those of shocks which are large. Thus, for instance, taking the 319 stronger earthquakes, which happened between 1902 and 1906 off the coasts of Japan, and whose land area of disturbance was, with a few exceptions, greater than 1,000 square *ri**, we find :—

Table X. Annual Variation of Stronger Submarine Earthquakes.

Month.	Number of Eqkes.	Month.	Number of Eqkes.
January.	25	July.	38
February.	39	August.	27
March.	25	September.	22
April.	19	October.	28
May.	28	November.	20
June.	21	December.	27

* 1 *ri* = 3.927 km. nearly.

The annual variation of these larger submarine earthquakes, illustrated in Fig. 12, indicates the maximum in February, and is, on the whole, opposite to that of the small shocks.

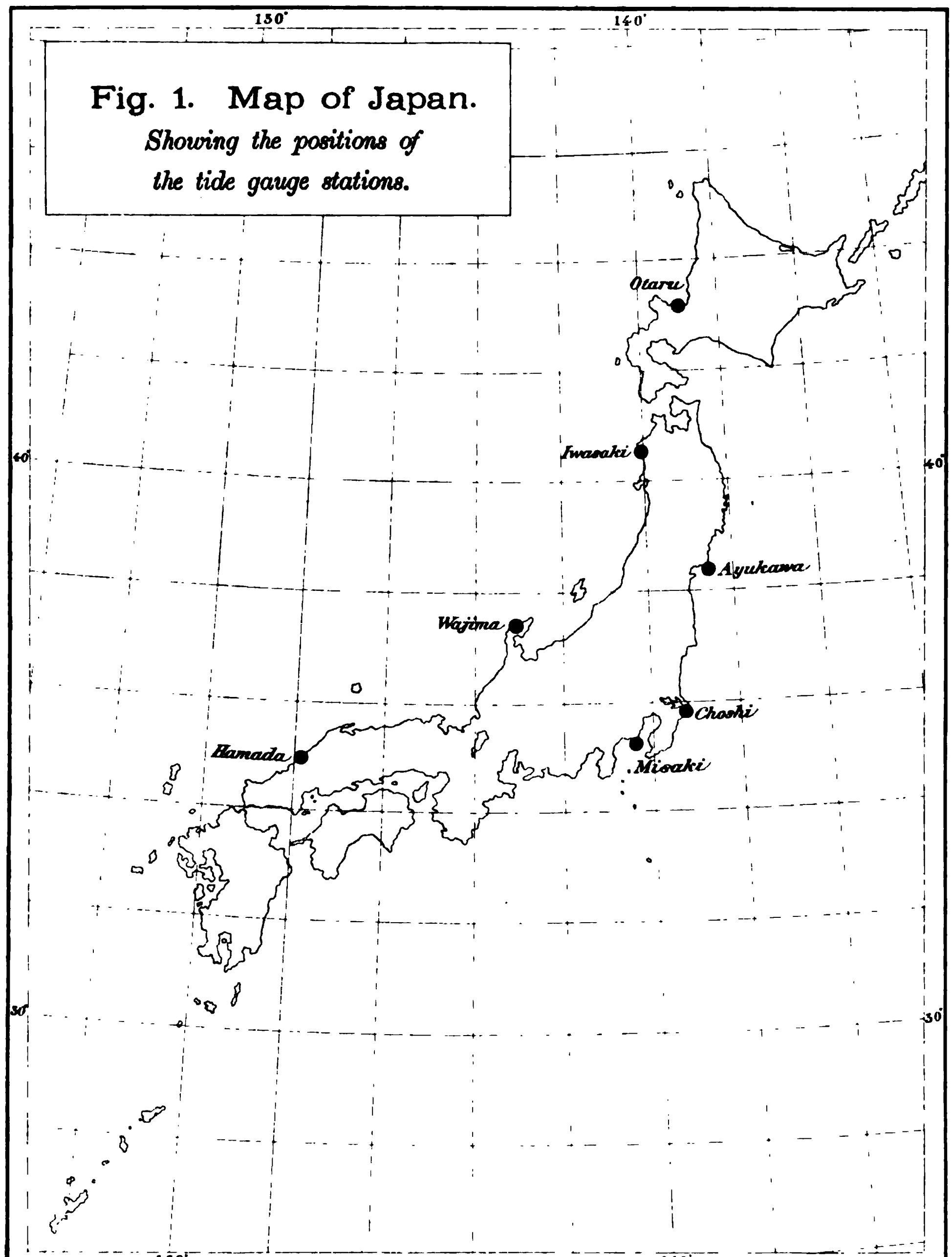


Fig. 1. Map of Japan.
Showing the positions of
the tide gauge stations.
130°
140°
40°
30°
Otaru
Iwasaki
Ayukawa
Wajima
Choshi
Misaki
Hamada

Annual Variation of the Height of
Sea Surface and the Atmospheric Pressure.

Ayukawa and *Misaki, 1903.*

Fig. 2. Atmospheric Pressure.

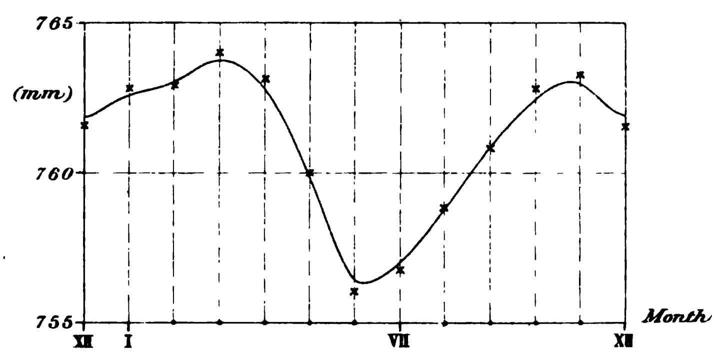
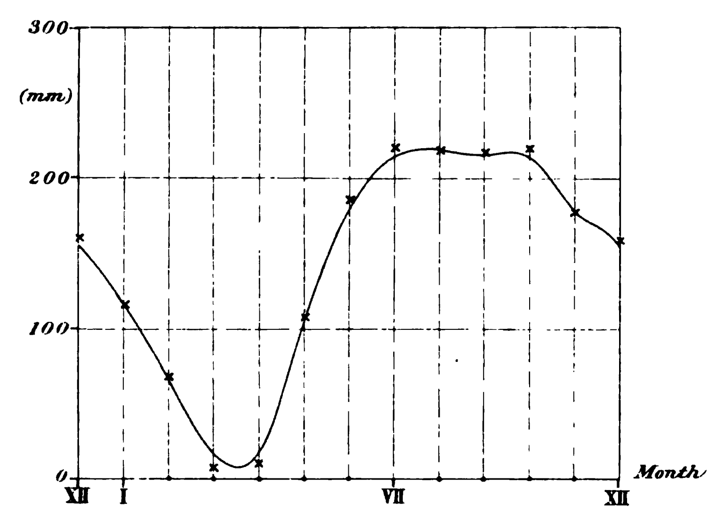


Fig. 3. Height of Sea Surface.



Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Choshi, 1904.

Fig. 4. Height of Sea Surface.

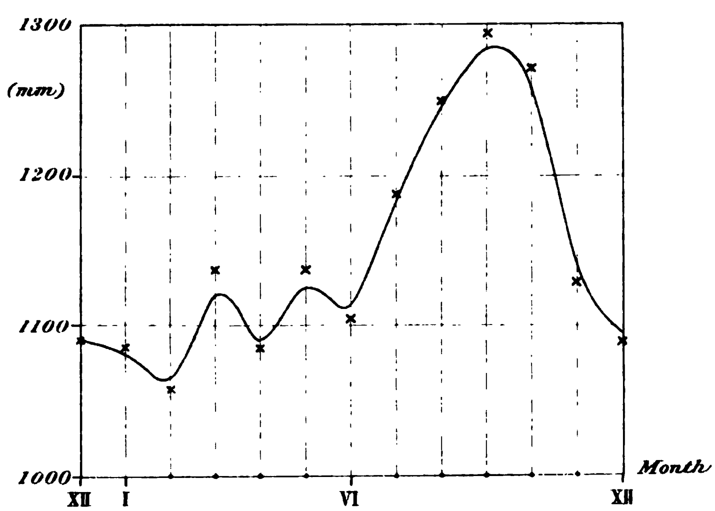
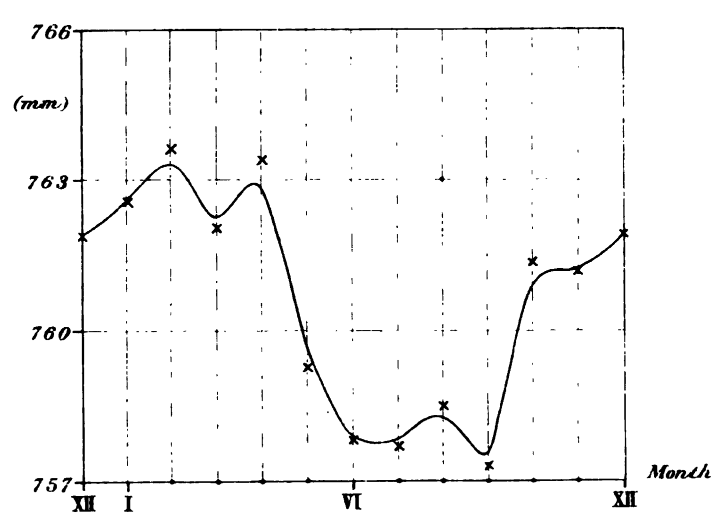


Fig. 5. Atmospheric Pressure.



Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Japan Sea Coast, 1902.

Fig. 6. Atmospheric Pressure.

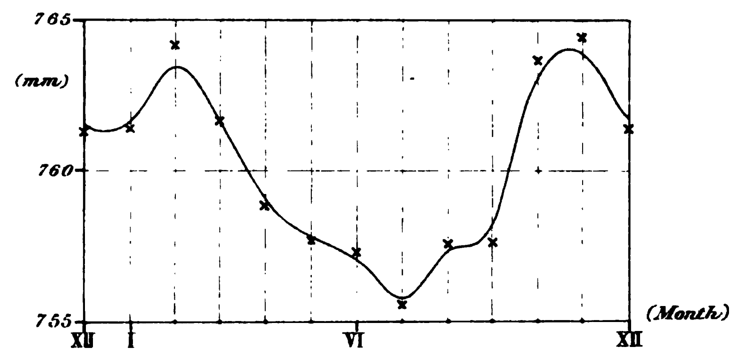
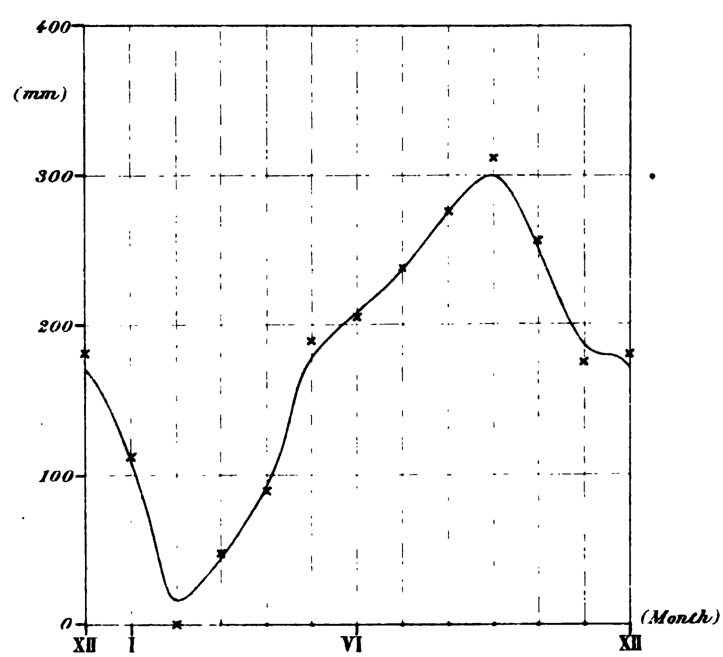


Fig. 7. Height of Sea Surface.



PL. XVIII.

Annual Variation of the Total Pressure at the Sea Bottom.

Fig. 8. *Ayukawa* and *Misaki*. *1902–1903*.

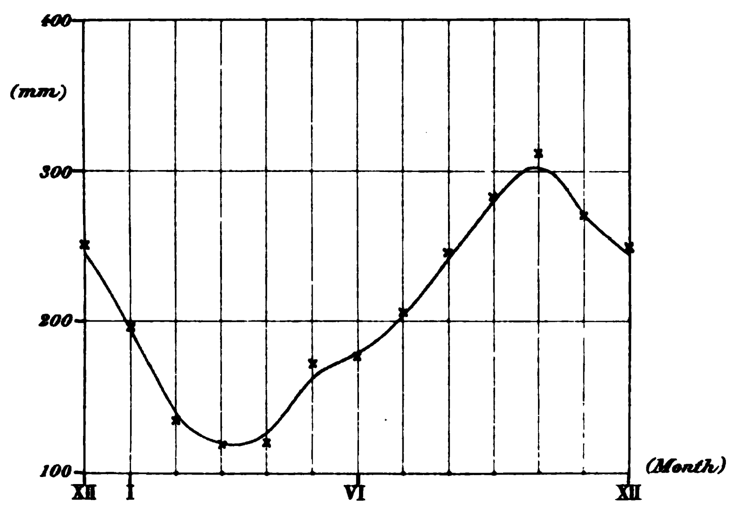
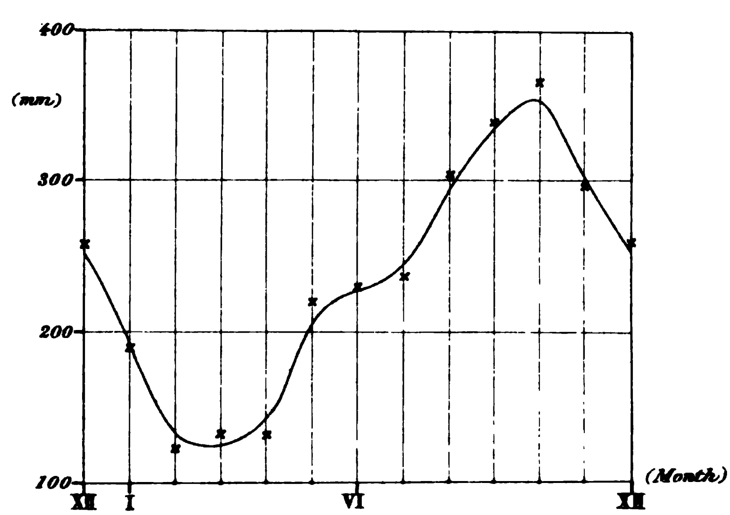


Fig. 9. *Japan Sea Coast*. *1902*.



Annual Variation.

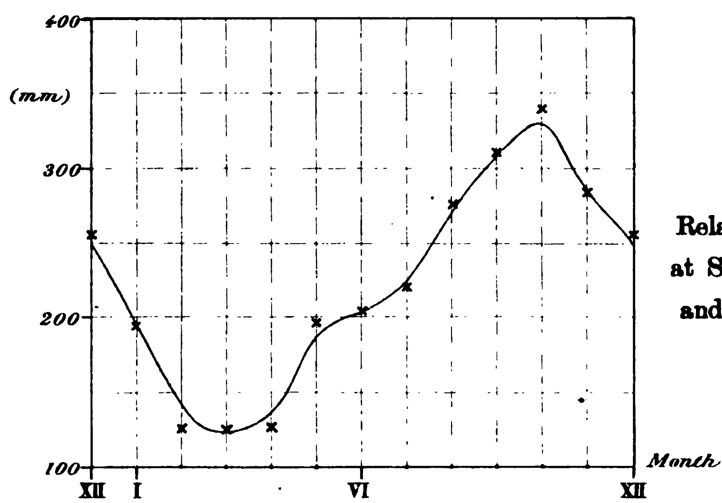


Fig. 10.
Relative Total Pressure at Sea Bottom. (Pacific and Japan Sea Coast.)

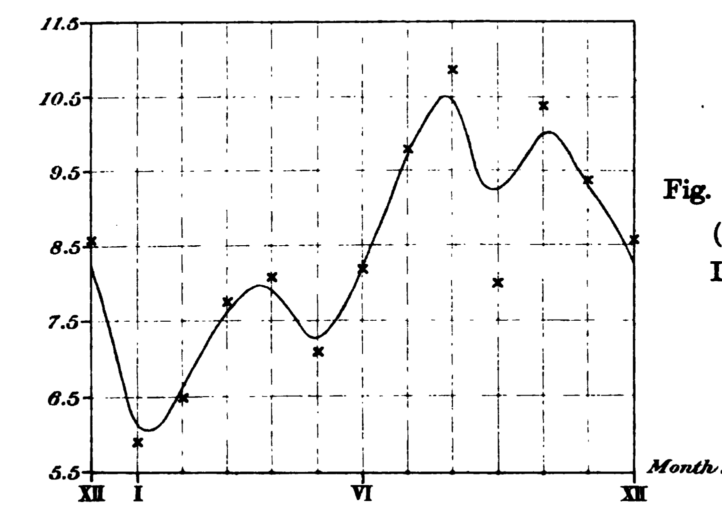


Fig. 11. Eqke Frequency. (Nemuro, Miyako, Ishinomaki, Kochi, and Hamada).

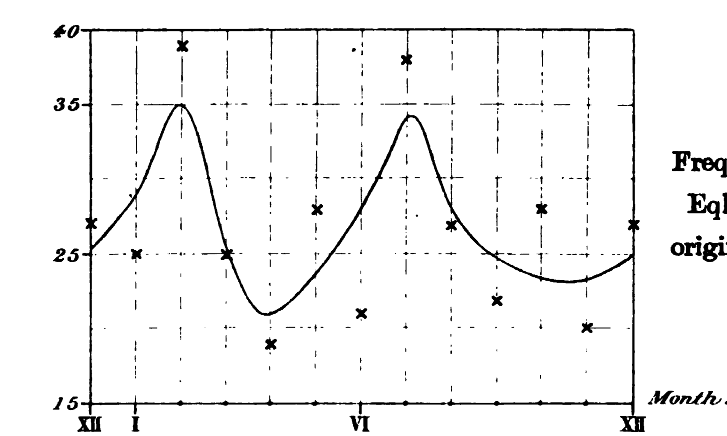


Fig. 12.
Frequency of Stronger Eqkes of submarine origin. (Whole Japan.)

Note on the Annual Variation of the Height of Level of Lake Biwa.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls XX-XXI.

The Lake of Biwa*, in the province of Omi, is the largest of the sort in Japan and is situated near the middle of the Main Island; its surface being about 86 metres above the mean sea level, and its area 46.5 square *ri*‡, or 717.2 sq. km. The observation of the water level along the coast of the lake was made, during the 12 years, 1893-1904, at 22 stations, to which, since 1905, nine more were added; the datum line being 282.53 *shaku* or 85.61 metres above the mean sea level at Tenpo-san, Osaka. The mean height of the surface of the lake water for each month during the 14 years, 1893-1906, obtained by taking the average of the measurements at the different places, is given in Table I.

From Table I it will be observed that the water was highest mostly in December and January; the amount of the fluctuation, or the difference between the maximum and minimum monthly heights, varying between 8.18 *shaku* (=248 cm) and 1.40 *shaku* (=42 cm.). The extreme monthly heights of the water level

* An account of the earthquake zones around the Biwa Lake has been given in the *Bulletin*, Vol. I, No. 3.

† 1 *ri*=36 *chō*=2.4 miles, or 3.927 km.

and their difference in each of the 14 years under consideration are given in Table II.

Table I. Mean Monthly Height of the Level of Lake Biwa*.
1893–1906.

Month. / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Mean.*
1893	2.74	2.82	2.68	3.71	3.93	3.90	2.62	1.76	2.00	2.69	2.86	2.41	2.84
1894	2.24	2.15	2.49	3.44	3.47	2.30	1.35	0.77	0.66	0.28	0.20	0.28	1.64
1895	0.61	0.98	2.01	2.39	1.78	1.49	3.12	6.18	3.99	2.84	2.10	1.44	2.41
1896	1.56	1.79	2.34	3.23	3.26	2.42	5.02	5.63	9.74	7.22	4.51	3.73	4.20
1897	3.05	2.92	2.67	3.52	3.98	3.05	2.80	2.05	2.59	3.72	2.24	1.77	2.86
1898	1.90	2.30	2.40	2.28	1.95	2.12	2.69	1.52	1.71	1.50	0.96	1.13	1.87
1899	1.67	2.19	3.45	3.07	2.21	2.02	2.15	1.83	3.18	4.29	2.95	1.79	2.57
1900	1.49	1.62	1.60	2.72	3.16	1.93	1.76	1.62	1.80	2.77	2.23	1.90	2.05
1901	1.74	1.48	1.25	1.71	1.44	0.76	2.56	1.70	0.83	0.24	0.17	0.04	1.16
1902	-0.05	0.06	0.47	1.10	2.23	1.99	1.62	2.33	1.15	1.23	0.41	-0.11	1.01
1903	0.31	1.78	0.83	2.10	2.40	2.34	4.27	2.90	0.52	0.56	0.35	0.43	1.56
1904	0.45	0.24	0.58	0.48	0.91	0.91	2.22	1.24	1.52	1.92	0.94	0.80	1.02
1905	1.33	1.41	1.69	1.37	1.17	1.29	2.93	2.30	1.73	0.37	0.08	-0.02	1.30
1906	1.00	1.55	1.90	1.27	0.61	0.67	2.01	1.17	1.05	1.55	1.25	0.78	1.23
Mean.	1.43	1.66	1.88	2.31	2.32	1.94	2.65	2.36	2.32	2.23	1.52	1.17	1.98

* The heights are expressed in *shaku* (1 *shaku* = 1/3.3 metre), the datum line being 282.53 *shaku* above the mean sea level at Tenpo-san, Osaka.

Annual Variation: the Height of Surface of Lake Biwa compared with the Amount of Precipitation and Barometric Pressure.

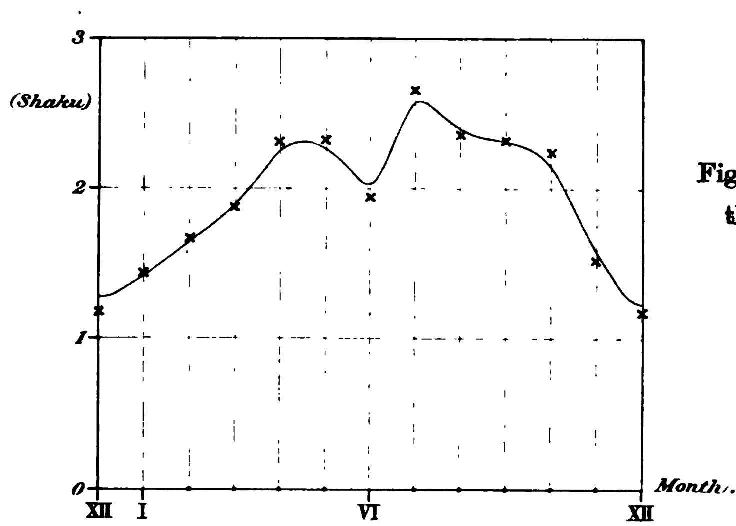


Fig. 1. Height of the Surface of Lake Biwa.

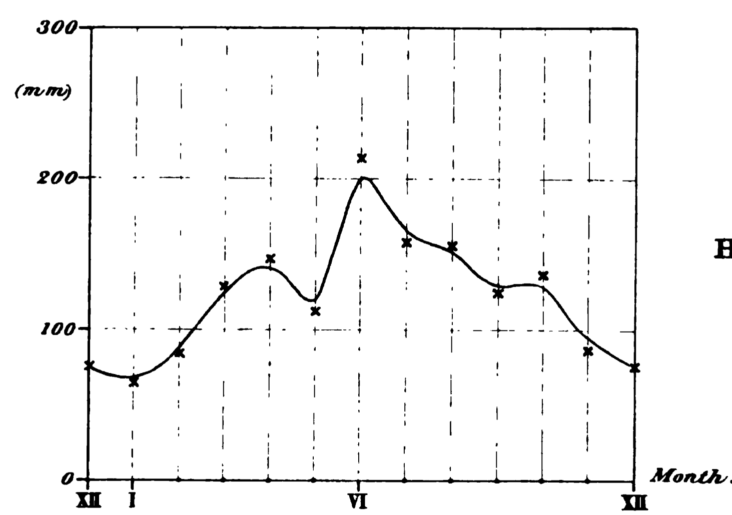


Fig. 2. Precipitation at Hikone and Kyoto

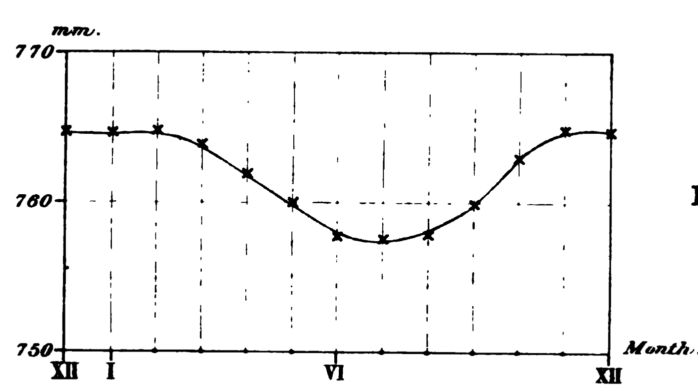


Fig. 3. Barometric Height at Hikone.

Annual Variation of the Seismic Frequency and the Pressure at the Lake Bottom.

Fig. 4. Seismic Frequency at Hikone.

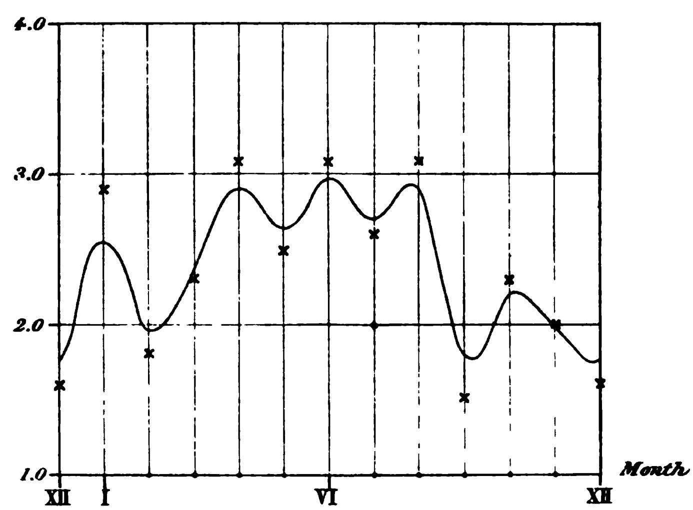


Fig. 5. Total Pressure at the Lake Bottom.

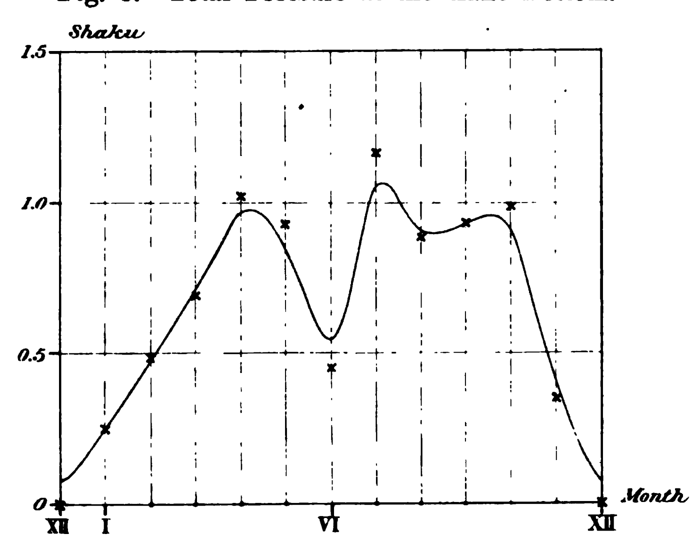


Table II. Maximum and Minimum Heights of the Lake Water.

Year	Maximum Height.		Minimum Height.		Difference.
	shaku		*shaku*		*shaku*
1893	3.93	(May)	1.76	(Aug.)	2.17
1894	3.47	(„)	0.20	(Nov.)	3.27
1895	6.18	(Aug.)	0.61	(Jan.)	5.57
1896	9.74	(Sept.)	1.56	(„)	8.18
1897	3.98	(May)	1.77	(Dec.)	2.21
1898	2.69	(July)	0.96	(Nov.)	1.73
1899	4.29	(Oct.)	1.67	(Jan.)	2.62
1900	3.16	(May)	1.49	(„)	1.67
1901	2.56	(July)	0.04	(Dec.)	2.52
1902	2.33	(Aug.)	−0.11	(„)	2.44
1903	4.27	(July)	0.31	(Jan.)	3.96
1904	2.22	(„)	0.24	(Feb.)	1.98
1905	2.93	(„)	0.02	(Dec.)	2.95
1906	2.01	(„)	0.61	(May)	1.40

In the following table I give the average heights of the lake water for the different months of the year deduced from Table I, and also the mean monthly barometric heights observed at the meteorological observatory of Hikone, which is situated on the south-eastern coast of Lake Biwa.

Table III. Annual Variations of the Height of Lake Water, and of the Barometric Pressure at Hikone.

Month.	Lake Level		Barometric Pressure.			Total pressure at the Lake Bottom.	
	(i) mean Height.	(ii) Relative Height.	(iii) Monthly mean.	(iv) Variation.	(v) Same as (iv), expressed in equivalent column of water.	(vi) Sum of (ii) and (v)	(vii) Relative Variation.
	shaku	*shaku*	mm	mm	*shaku*	*shaku*	*shaku*
I	1.43	**0.26**	764.5	6.9	0.31	0.57	**0.25**
II	1.66	**0.49**	64.7	7.1	0.32	0.81	**0.49**
III	1.88	**0.71**	63.9	6.3	0.28	0.99	**0.67**
IV	2.31	**1.14**	61.9	4.3	0.19	1.33	**1.01**
V	2.32	**1.15**	59.8	2.2	0.10	1.25	**0.93**
VI	1.94	**0.77**	57.6	0.0	0.00	0.77	**0.45**
VII	2.65	**1.48**	57.6	0.0	0.00	1.48	**1.16**
VIII	2.36	**1.19**	57.8	0.2	0.01	1.20	**0.88**
IX	2.32	**1.15**	59.8	2.2	0.10	1.25	**0.93**
X	2.23	**1.06**	63.0	5.4	0.24	1.30	**0.98**
XI	1.52	**0.35**	64.8	7.2	0.32	0.67	**0.35**
XII	1.17	**0.00**	64.7	7.1	0.32	0.32	**0.00**

With regard to the annual variation of the lake level, we see, from (ii), Table III, that the difference between the maximum and minimum monthly heights was 1.48 *shaku* (=44.9 cm.), the corresponding change in the volume of the water of the lake being $10^8 \times 3.22$ cubic metres or about 0.322 cubic km.

As will be seen from the graphical illustration in Fig. 1 (Pl. XX), the level was higher in April to October than during the other months, and its annual variation is nearly opposite to that of the barometric pressure (Fig. 2). The amount of fluctua-

tion of the monthly mean of the latter is, however, only 7.2 mm of mercury (=0.32 *shaku* of water), or about one-fifth of that of the former; the annual variation of the lake level depending probably almost entirely on the precipitation in the surrounding districts.

The following table gives the average monthly amount of precipitation at Hikone and at Kyoto, the latter place being situated some distance to the south-west of the Lake of Biwa.

Table IV. Precipitation at Hikone and Kyoto.

Month.	Hikone	Kyoto	*Mean*
	mm	mm	mm
January	76.8	52.4	64.6
February	107.4	62.7	85.1
March	145.0	114.3	129.7
April	126.1	168.3	147.2
May	77.0	148.3	112.7
June	188.7	240.5	214.6
July	135.5	182.7	159.1
August	189.7	120.9	155.3
September	93.4	157.4	125.4
October	137.4	135.8	136.6
November	82.7	86.6	84.7
December	101.5	50.1	75.8

As illustrated in Fig. 2, the annual variation of the precipitation at Kyoto and Hikone is very similar to that of the height of the lake surface (Fig. 1).

Annual variation of seismic frequency at Hikone. The monthly number of earthquakes observed instrumentally at

the meteorological observatory of Hikone, between 1894 and 1907, are as follows.

Table V. Monthly Earthquake Numbers at Hikone.

Month / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Sum.*
1894	20*	6	3	0	2	7	8	9	1	4	3	6	69
1895	11	1	2	6	2	1	5	1	7	7	2	6	51
1896	4	1	2	10	6	13	9	8	1	1	1	2	58
1897	3	3	4	7	3	1	0	6	1	2	1	0	31
1898	1	0	0	2	0	0	0	4	0	1	2	0	10
1899	3	2	6	2	5	2	1	0	0	0	4	1	26
1900	1	0	2	1	2	3	2	1	3	6	7	3	31
1901	2	2	1	1	1	1	2	0	2	0	4	0	16
1902	2	1	3	0	2	4	2	1	2	1	1	0	19
1903	1	1	3	0	0	0	4	1	0	0	1	1	12
1904	1	0	1	1	2	3	0	1	1	1	1	0	12
1905	1	1	1	0	0	4	0	5	1	4	0	3	20
1906	6	3	1	5	5	1	3	5	1	2	0	0	32
1907	2	4	3	8	5	4	1	1	1	3	1	0	33
Mean.	2.9	1.8	2.3	3.1	2.5	3.1	2.6	3.1	1.5	2.3	2.0	1.6	

As shown in Fig. 4 (Pl. XXI), the annual variation of the seismic frequency at Hikone indicates the maximum in August, differing in this respect from those for the other stations, such as Kyoto, Nagoya, and Kumamoto, which are shaken more by earthquakes of inland origin, and whose seismic frequency is generally minimum in Summer‡. Now, according to Table III,

* Excluded in deducing the mean frequency, being due to the abundance of after-shocks of the severe Mino-Owari earthquake of Jan. 10, 1894.

‡ See the "Publications," No. 8.

the total pressure at the lake bottom, or the sum of the water and atmospheric pressures, is maximum in July, and its annual variation is somewhat similar to that of the height of the water level. The change of pressure at the bottom of the lake, whose mean annual amplitude is 1.16 *shaku* (=35 cm), or 3.6 times greater than that of the barometric pressure, may possibly be the cause of the annual variation of the seismic frequency peculiar to Hikone.

List of the Stronger Japan Earthquakes, 1902-1907.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

The total number of earthquakes, which originated in or about Japan during the last six years, 1902 to 1907, was 9,628, giving the average yearly frequency of 1,605, as follows .—

Year.	Number of eqkes.
1902	1,488
1903	1,349
1904	1,230
1905	1,963
1906	1,792
1907	1,806

Among these earthquakes which were mostly slight and local, there were 621*, which were extensive, and whose land area of motion, as observed with ordinary Gray-Ewing-Milne type seismographs, was over 1,000 square *ri* (1 *ri*=3.927 km). The annual frequency of these larger earthquakes varied between 76 and 132, as follows :—

* Including a few typical earthquakes of inland origin, whose area was between 500 and 1,000 sq. *ri*.

Monthly and Yearly Numbers of Larger Earthquakes.

Whole Japan. 1902—1907.

Year. / Month.	1902	1903	1904	1905	1906	1907	*Sum.*
January.	10	5	2	7	14	7	45
February.	13	11	2	14	8	5	53
March.	11	10	10	6	20	15	72
April.	4	5	9	7	14	12	51
May.	13	2	10	5	19	9	58
June.	5	4	9	29*	3	4	54
July.	8	10	13	14	7	8	60
August.	4	7	8	9	10	6	44
September.	8	8	6	13	5	8	48
October.	4	3	8	12	12	11	50
November.	7	5	6	5	10	9	42
December.	8	6	6	11	6	7	44
Sum.	95	76	89	132	128	101	621

The unusually large monthly number of 29 for June 1905 (marked with an *asterisk*) was due to the occurrence of the strong O-shima and Inland Sea earthquakes and their after-shocks. The average yearly seismic frequency is about 104, or at the rate of nearly twice per week.

The land area of sensible motion of the 621 earthquakes under consideration varied between about 100 sq. *ri* to over 20,000 sq. *ri*, the numbers of the shocks of different extension being as shown in the following table.

Numbers of Earthquakes of Different Land Areas of *Sensible Motion.*

Land area of sensible motion.	Number of earthquakes.	Land area of sensible motion.	Number of earthquakes
under 500 sq. ri.	58	7,501— 8,000 sq. ri.	6
501—1,000	112	8,001— 8,500	7
1,001—1,500	86	8,501— 9,000	4
1,501—2,000	82	9,001— 9,500	1
2,001—2,500	59	9,501—10,000	1
2,501—3,000	36	10,001—10,500	3
3,001—3,500	35	10,501—11,000	4
3,501—4,000	23	11,001—11,500	1
4,001—4,500	22	11,501—12,000	2
4,501—5,000	16	12,001—12,500	1
5,001—5,500	15	12,501—13,000	0
5,501—6,000	19	13,001—13,500	0
6,001—6,500	8	13,501—14,000	1
6,501—7,000	10	14,001—14,500	1
7,001—7,500	7	14,501—15,000	0
		⋮	⋮
		20,501—21,000	1

Confining our attention to those earthquakes, whose land area of *sensible* motion was over 500 sq. *ri*, we see from the above table that the areas of the majority of these are included between 501 and 6,000 sq. *ri*. Especially, the earthquakes of the area between 501 and 2,000 sq. *ri* were numerous, and their total number, namely, 280, is very nearly equal to that of all the

shocks of the area between 2,001 and 21,000 sq. *ri*, namely, 283. Very extensive disturbances happened of course not very frequently, and there were only 16 earthquakes, whose area of sensible motion was over 9,001 sq. *ri*.

Pl. XXII graphically illustrates the variation of the frequency of earthquakes of the different land areas of sensible motion. The mean curve seems to be approximately a logarithmic curve, becoming quickly asymptotic with the increase of the area.

The accompanying list, which has been compiled, with a few corrections, from the seismological notes in the successive monthly numbers of the "Kisho Yoran" (*Weather Review*) published by the Central Meteorological Observatory, gives for each of the 621 strong and moderate earthquakes under question, the following particulars :—

(1). Date.

(2). Approximate time of earthquake occurrence at the epicentre. The time used is that of longitude 135° E. of Greenwich, namely, the 1st Normal Japan Time.

(3). Approximate indication of the position of the earthquake origin.

(4), (5). Longer and shorter axes of the land area, within which the motion was intense enough to be recorded by the ordinary Gray-Ewing-Milne type seismographs, the seismic disturbance being *sensible* only in a portion of the region thus determined.

(6). Land area of disturbance of *strong* motion.

(7). ,, ,, ,, ,, ,, *moderate* ,,

(8). ,, ,, ,, ,, ,, *slight* ,,

(9). Total land area, within which the earthquake motion was *sensible* this being equivalent to the sum of (6), (7), and (8).

The length and area are expressed in *ri* and square *ri* respectively. These may be converted into kilometers and miles by the following relations :—

$$\begin{cases} 1\ ri = 3.93\ \text{km} = 2.44\ \text{miles.} \\ 1\ \text{sq.}\ ri = 15.42\ \text{sq. km} = 5.96\ \text{sq. miles.} \end{cases}$$

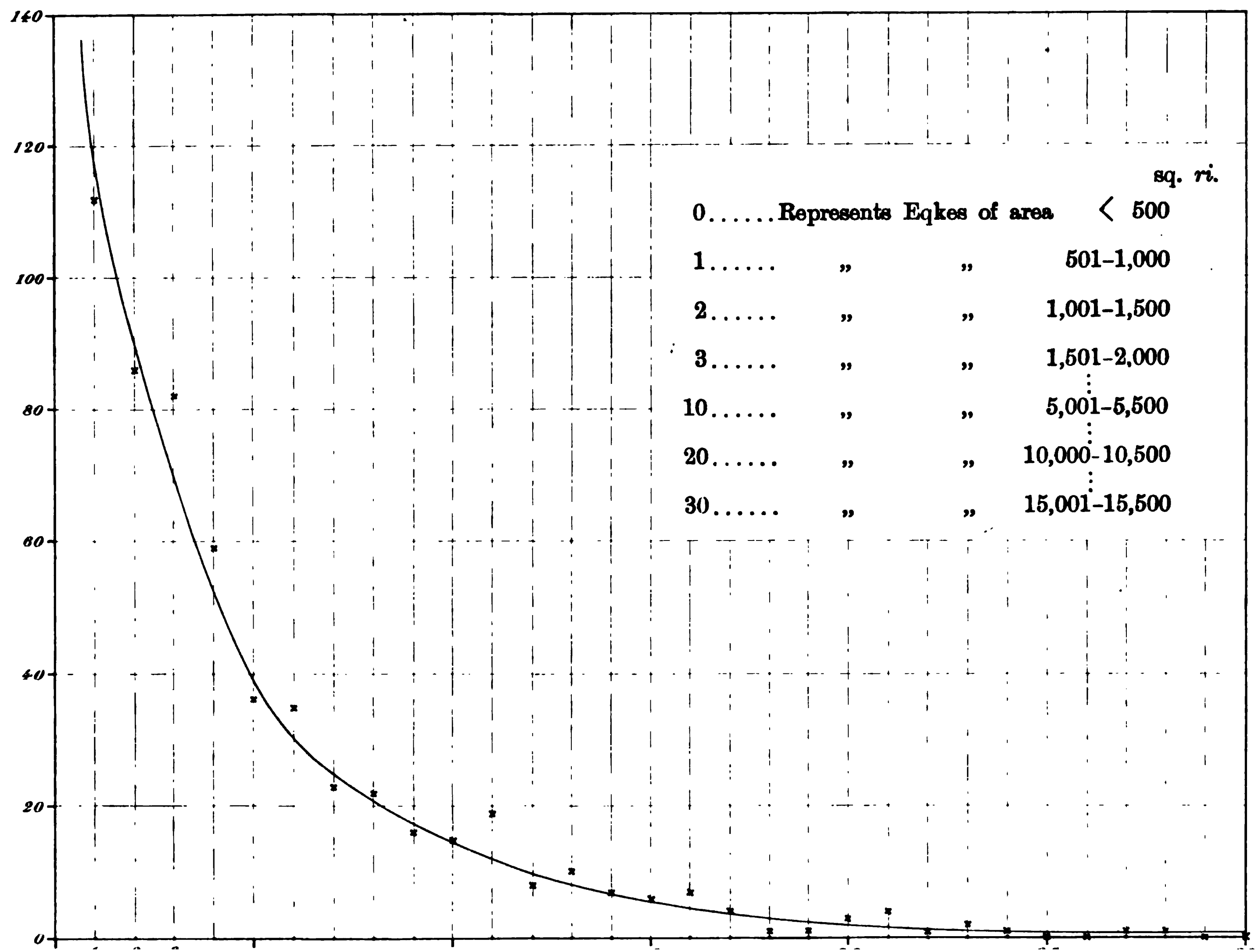
For the names and positions of the different provinces, the reader is referred to the key map of Japan given in the "Bulletin," Vol. I, Pl. XXVII.

The intensity of ordinary, or non-destructive, sensible motion is here indicated as "strong," "moderate," or "slight." A "slight" shock is one which is very feeble and just strong enough to be felt; a "moderate" shock is one whose motion is well pronounced, but not so severe as to cause general alarm; and, finally, a "strong" shock is one which is sufficiently intense to cause people to run out of doors, to throw down furnitures, to produce slight cracks of walls, etc.

621 STRONGER JAPAN EARTHQUAKES. **1902-1907.**

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1902			*ri.*	*ri.*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Jan. 1	$0^h 20^m$ a.m.	Off the E. coast of Mutsu.	250	100	—	400	2,700	3,100
3	1 40 a.m.	Boundary between Kii and Yamato.	140	80	190	380	1,230	1,800
4	6 09 a.m.	Off the coast of Hitachi.	160	120	—	1,050	3,850	4,900
5	4 04 p.m.	Vicinity of Mito (Hitachi).	70	60	—	250	1,500	1,750
14	9 01 a.m.	S. part of Hida.	110	70	—	250	2,550	2,800
17	4 18 a.m.	Central part of Sagami.	100	50	70	230	1,500	1,800
18	4 38 a.m.	Off the E. coast of Mutsu.	250	150	200	1,900	4,850	6,950
29	11 25 p.m.	" " coast of Hitachi.	200	100	—	1,450	5,600	7,050
30	11 01 p.m.	" " E. coast of Mutsu. $\varphi=39°09'N, \lambda=143°31'E.$	350	250	2,000	5,400	6,300	13,700
31	10 42 a.m.	Off the coast of Mutsu. $\phi=40°50'N, \lambda=144°13'E.$	280	220	650	3,950	6,000	10,600

Frequencies of the Earthquakes whose
Land Area of Sensible Motion was over 500 sq. *ri.*



(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1902			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Feb. 2	2^h52^m a.m.	Off the coast of Rikuchū.	120	60	—	280	1,620	1,900
6	7 18 a.m.	City of Kumamoto (Higo.)	60	20	—	460	510	970
„	9 05 p.m.	„	70	60	—	750	1,150	1,900
7	10 01 p.m.	Off the E. coast of Mutsu.	180	100	—	270	3,670	3,940
8	0 31 p.m.	„ of Nemuro.	80	50	190	40	460	690
11	11 50 p.m.	Bay of Owari.	40	20	—	190	420	610
17	8 30 p.m.	Off the coast of Hitachi.	100	80	—	580	1,380	1,960
20	10 50 a.m.	Hachijō-jima.	190	150	—	650	6,550	7,200
21	0 35 a.m.	Off the E. coast of Mutsu.	260	170	370	2,960	7,400	10,730
„	8 29 a.m.	Do.	200	110	10	1,000	4,580	5,590
26	10 19 a.m.	Off the coast of Rikuchū.	190	130	—	770	2,660	3,430
27	0 01 p.m.	„ Hidaka.	130	80	—	220	2,330	2,550
„	11 18 p.m.	„ Iwaki.	140	60	60	620	2,560	3,240
28	5 41 p.m.	N. part of Ise.	40	30	—	300	980	1,280
March 1	1 33 p.m.	Off the coast of Rikuchū.	140	120	—	380	2,640	3,020
„	8 23 p.m.	N. part of Yamato.	70	50	90	330	1,330	1,750
3	9 13 a.m.	Vicinity of Sahara (Shimosa).	180	160	—	1,500	6,550	8,050
„	10 37 p.m.	Tsugaru Strait.	140	70	10	430	2,550	2,990
6	9 35 p.m.	Kii Channel.	50	30	90	190	650	930
10	2 35 p.m.	W. part of Hitachi.	150	120	—	2,000	3,970	5,970
12	10 48 a.m.	Uraga Channel.	70	60	—	190	1,500	1,690
20	10 59 a.m.	Tainan (Formosa).	500	200	50	200	2,250	2,500
„	11 19 a.m.	Do.	200	100	—	600	1,400	2,000
23	6 17 p.m.	Central part of Settsu.	90	60	70	1,550	1,590	3,210
25	2 35 p.m.	Vicinity of Sahara (Shimosa).	220	180	240	2,520	5,150	7,910
April 1	5 32 a.m.	E. part of Sagami.	100	40	—	240	2,290	2,530

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum.*
1902			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
April. 5	7h 23m p.m.	Bay of Tōkyō. $\varphi=35°\ 26'$ N, $\lambda=139°\ 45'$ E	130	100	—	2,050	3,580	5,630
6	2 13 a.m.	Bay of Tōkyō. $\varphi=35°\ 31'$ N, $\lambda=139°\ 49'$ E	70	60	—	870	1,130	2,000
19	9 17 a.m.	N part of Mino.	70	50	30	270	1,450	1,750
May 2	8 31 p.m.	Off the coast of Rikuchu.	250	200	—	1,360	2,750	4,110
5	7 05 a.m.	Karita-county, Iwaki.	60	40	10	240	800	1,050
6	8 33 a.m.	Off the E. coast of Kii.	100	40	—	320	1,760	2,090
8	11 19 a.m.	Vicinity of Tanega-shima.	200	100	740	1,170	2,710	4,620
15	7 38 a.m.	Vicinity of Kasumiga-ura.	40	30	70	210	870	1,150
16	9 39 a.m.	Koshi-county, Echigo.	90	60	—	430	2,620	3.050
17	1 18 p.m.	Off the coast of Hitachi.	90	70	—	360	1,320	1,680
24	5 03 a.m.	S. part of Ise.	60	50	40	530	870	1,440
„	11 30 p.m.	N. part of Ise.	100	80	90	1,570	2,350	4.010
25	8 29 p.m.	Minamitsuru county, Kai.	160	130	390	1,620	3,810	5,820
„	9 07 p.m.	Do.	120	80	110	790	3,420	4,320
„	10 15 p.m.	Do.	70	50	70	370	1,610	2,050
28	6 02 p.m.	S. part of Kushiro.	350	200	430	1,560	5,650	7,640
June 2	9 28 p.m.	Off the S. coast of Kii.	120	80	200	900	1,500	2,660
13	9 22 a.m.	Off the S. coast of Kushiro.	300	200	300	1,500	6,100	7,900
20	5 49 p.m.	Sano (Shimotsuke).	180	150	470	1,660	6,170	8.300
23	7 42 a.m.	Bay of Tokyō. $\varphi=35°\ 26'$N, $\lambda=139°\ 50'$E	190	160	450	1,830	5,220	7,500
29	2 29 a.m.	Off the coast of Rikuchu.	200	150	—	840	2,820	3,660
July 1	2 01 a.m.	N. part of Sagami.	100	80	—	540	2,800	3,340
„	5 19 p.m.	Off the coast of Rikuchu.	260	180	—	1,080	3,840	4,920
8	11 05 p.m.	„ E. coast of Mutsu.	300	200	160	1,840	6 000	8,000

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1902				ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
July	9	$2^h 42^m$ a.m.	Off the coast of Amakusa (Higo).	50	40	—	470	900	1,370
	10	7 57 p.m.	„ Mutsu	250	150	—	1,400	4,350	5,750
	11	8 57 a.m.	„ Izu.	130	80	—	260	2,190	2,450
	„	10 03 a.m.	„ NE coast of Nemuro.	300	150	—	200	3,200	3,400
	26	7 51 a.m.	„ E coast of Awa peninsula.	180	100	—	380	3.170	3,550
Aug.	7	0 36 p.m.	Bay of Tokyo.	160	70	—	720	3,550	4,270
	„	6 22 p.m.	Off the coast of Mutsu.	250	150	—	280	5,320	5,600
	8	8 37 a.m.	Sahara (Shimosa).	200	120	60	480	3,890	4,430
	19	8 43 p.m.	Off the coast of Hidaka.	130	80	—	290	1,570	1,860
Sept.	3	11 55 a.m.	Off Kinkazan (Rikuzen).	150	100	10	600	2,790	3,400
	4	10 57 p.m.	Off the coast of Awa (Shikoku).	80	60	130	830	920	1,880
	16	3 19 a.m.	Nakano (Sagami).	70	40	—	100	1,550	1,650
	17	6 23 p.m.	Sea of Iyo.	60	30	—	150	1,180	1,330
	22	5 43 a.m.	Off Kinkazan (Rikuzen).	180	100	170	1,130	3,400	4,700
	23	11 30 p.m.	Sea of Aki.	60	50	210	740	1,240	2,190
	26	11 51 a.m.	Hachiman (Mino).	60	40	—	280	1,120	1,400
	28	8 18 p.m.	Off the coast of Tokachi.	250	100	—	200	1,850	2,050
Oct.	5	4 24 p.m.	Bay of Iburi.	170	90	—	1,200	3,900	5,100
	12	10 24 a.m.	Bay of Tōkyō.	70	40	—	430	1,200	1,630
	16	1 57 a.m.	Off the coast of Hitachi.	100	70	—	650	1,950	2,600
	25	9 33 a.m.	„ Iwaki.	100	80	—	980	1,380	2,360
Nov.	5	5 49 p.m.	Vicinity of Tsukuba-San (Hitachi).	50	40	—	120	930	1,050
	6	11 17 a.m.	Vicinity of Etrup Island.	300	200	—	100	1,770	1,870

(1) Date.	(2) Time of occurrence	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1902			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Nov. 7	$3^h 58^m$ p.m.	Off the coast of Iwaki.	70	60	—	340	1,380	1,720
13	4 31 a.m.	Kanayama (Mino).	50	30	—	280	1,070	1,350
„	8 15 a.m.	Off Chōshi (Shimosa).	80	70	—	20	1,330	1,350
20	8 35 a.m.	Off the coast of Iwaki.	120	90	260	990	2,550	3,800
21	4 03 p.m.	Vicinity of Kōshun (Formosa).	200	100	200	800	1,300	2,300
Dec. 6	6 12 a.m.	Tainan (Formosa).	120	60	—	750	750	1,500
„	0 47 p.m.	Off the coast of Iwaki.	100	90	—	480	2,040	2,520
„	3 59 p.m.	Do.	90	70	—	150	1,170	1,320
9	1 53 a.m.	Sugito (Musashi.)	80	40	60	900	1,340	2,300
11	5 06 a.m.	Vicinity of Yaku-shima.	150	100	30	780	790	1,600
14	1 57 p.m.	Mizukaido (Shimosa).	170	100	200	2,200	4,790	7,190
17	9 49 a.m.	Off the coast of Iwaki.	100	80	120	230	2,000	2,350
31	2 38 p.m.	Mizukaido (Shimosa). $\varphi=35°\ 59'N,\ \lambda=139°\ 55'E$	250	120	360	2,450	5,980	8,790
1903								
Jan. 2	5 27 p.m.	Off the coast of Iyo.	120	60	220	1,060	2,780	4,060
5	8 44 a.m.	Shimosa.	70	30	—	210	1,190	1,400
18	9 13 p.m.	Off the coast of Hidaka.	220	130	70	990	2,960	4,020
30	1 41 p.m.	Do.	140	90	—	450	3,300	3,750
31	1 47 a.m.	Off the SE. coast of Awa Peninsula.	250	180	—	300	8,200	8,500
Feb. 3	2 55 a.m.	Off the SE. coast of Nemuro.	250	100	—	150	1,370	1,520
„	4 59 a.m.	Vicinity of Saruhashi (Kai).	100	40	10	760	2,060	2,830
„	9 14 p.m.	Some distance off the coast of Iwaki.	350	200	100	2,450	9,350	11,900
8	4 45 a.m.	Off the coast of Sendai.	180	90	130	810	5,160	6,100
13	0 45 p.m.	„ Hitachi.	90	60	30	440	1,480	1,950
14	4 48 p.m.	„ Iwaki.	130	60	70	680	1,960	2,710

(1) Date	(2) Time of occurrence	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1903			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Feb. 18	11^h36^m a.m.	Off the coast of Iwaki.	90	60	—	200	1,950	2,150
20	7 30 p.m.	„ Mutsu.	130	90	—	290	1,030	1,320
23	11 44 p.m.	Vicinity of Ashio (Shimotsuke)	70	50	—	300	2,270	2,570
26	0 19 a.m.	Off the coast of Iwaki.	150	80	—	800	2,770	3,570
28	7 07 p.m.	„ Higo.	80	60	9	1,240	1,440	2,770
March 12	5 35 a.m.	Vicinity of Sekiyado (Shimosa).	90	40	—	380	2,010	2,390
„	9 11 p.m.	Bungo Strait.	120	90	60	940	2,710	3,710
13	1 11 p.m.	Vicinity of Tochigi (Shimotsuke).	50	30	—	190	1,990	2,180
„	3 04 p.m.	Vicinity of Kanagawa (Musashi).	110	50	—	300	2,630	2,930
21	7 36 p.m.	Off the coast of Suō.	270	150	1,210	4,610	6,640	12,460
„	11 57 p.m.	Do.	80	50	—	430	2,070	2,500
22	6 12 a.m.	Do.	90	50	—	450	2,270	2,720
26	0 59 a.m.	„ Awa peninsula.	130	60	—	190	1,730	1,920
„	8 21 a.m.	„ Rikuzen.	180	120	—	110	5,860	5,970
31	11 01 a.m.	Do.	200	100	—	450	4,320	4,770
April 1	11 09 p.m.	Do.	200	80	—	1,220	4,430	5,650
17	4 08 a.m.	„ E. coast of Nemuro.	120	60	230	450	680	1,360
19	7 48 p.m.	„ coast of Kazusa.	110	70	—	510	1,310	1,820
21	8 50 p.m.	Saruhashi (Kai).	90	40	10	450	2,050	2,510
22	5 02 a.m.	Boundary between Shimosa and Shimotsuke.	120	50	140	1,200	2,200	3,540
May 6	8 52 a.m.	Do.	80	40	—	230	1,440	1,670
10	3 19 a.m.	Off the coast of Iwaki.	170	110	270	1,400	2,880	4,550
June 2	7 59 p.m.	„ E. coast of Mutsu.	150	90	—	430	1,110	1,540

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1903			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
June 3	0^h28^m p.m.	Vicinity of Hachijo-jima.	180	100	20	270	2,530	2,820
7	8 38 a.m.	Boundary between Shimosa and Shimotsuke.	50	30	—	290	730	1,020
„	6 07 p.m.	Giran (Formosa).	350	?	850	1,400	150	2,400
July 1	9 10 a.m.	Off the coast of Hitachi.	300	180	660	3,270	6,630	10,560
3	2 20 a.m.	„ Hyuga.	70	60	—	300	850	1,150
6	3 19 a.m.	W. part of Hitachi.	80	60	—	680	1,710	2,390
„	1 59 p.m.	Sea of Ise.	220	120	500	3,050	5,360	8,910
9	3 00 p.m.	N. part of Sagami.	90	50	40	390	2,660	3,090
12	1 56 p.m.	Tainan (Formosa).	100	70	—	500	1,800	2,300
15	4 51 a.m.	Sano (Shimotsuke).	70	40	—	230	2,430	2,660
16	9 24 p.m.	Off the coast of Hyuga.	120	100	—	900	1,960	2,860
17	10 50 a.m.	Central part of Kii.	100	60	130	400	1,070	1,600
21	2 06 p.m.	Tochigi (Shimotsuke).	70	40	—	390	1,510	1,900
Aug. 10	1 40 p.m.	Hirayu, Yoshiki county, Hida.	100	50	40	530	3,300	3,870
„	1 46 p.m.	Do.	90	50	30	300	2,940	3,270
14	0 47 a.m.	Off the coast of Nemuro.	400	200	170	810	2,690	3,670
„	1 08 a.m.	Do.	400	100	—	290	1,480	1,770
„	10 16 a.m.	Do.	350	100	—	350	2,300	2,650
23	9 33 p.m.	Uraga Channel.	150	80	—	240	2,240	2,480
31	1 24 p.m.	Off the coast of Iwaki.	130	70	30	290	2,020	2,340
Sept. 3	1 26 a.m.	„ Rikuzen.	120	60	—	470	1,790	2,260
5	2 38 a.m.	Central part of Rikuchu.	60	30	—	380	630	1,010
7	4 14 p.m.	Off the coast of Taito (Formosa).	120	70	—	300	1,700	2,000
10	1 26 p.m.	„ Formosa.	80	50	—	480	610	1,090

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1903				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Sept.	10	5^h45^m p.m.	Taito (Formosa).	80	70	100	400	1,700	2,200
	18	7 44 p.m.	Off the coast of Hidaka.	230	140	20	920	4,410	5,350
	20	9 12 p.m.	„ Iwaki.	130	90	—	360	3,320	3,680
	21	7 33 p.m.	„ Rikuchu.	100	60	—	230	840	1,070
Oct.	11	1 41 a.m.	„ Hyuga.	140	100	470	1,160	1,660	3,290
	12	9 51 p.m.	„ Hidaka.	120	70	—	220	1,900	2,120
	27	9 57 p.m.	Tokyo Bay.	160	90	330	2,550	3,060	5,940
Nov.	1	6 35 a.m.	Taichu (Formosa).	70	50	—	150	970	1,120
	6	7 04 p.m.	Off Yokosuka in Tokyo Bay.	80	50	—	70	1,150	1,220
	10	5 51 p.m.	Tokyo Bay.	160	90	170	1,710	3,200	5,080
	20	4 17 p.m.	Off the coast of Iwaki.	190	140	920	2,490	4,250	7,660
	29	7 11 p.m.	Do.	80	50	50	340	1,180	1,570
Dec.	1	11 21 p.m.	Taichu (Formosa).	100	60	—	200	2,080	2,280
	3	5 52 p.m.	Off the coast of Osumi.	130	90	100	750	930	1,780
	9	8 55 a.m.	N. part of Shimosa.	35	30	—	140	1,150	1,290
	18	11 20 a.m.	Off the coast of Hitachi.	200	120	890	2,530	3,680	7,100
	28	11 25 p.m.	„ Kinkazan (Rikuzen).	180	100	—	620	3,880	4,550
	31	2 10 p.m.	Sea of Aki.	80	30	90	270	2,170	2,530
1904									
Jan.	19	5 47 a.m.	Off the E. coast of Rikuzen.	80	60	—	230	1,010	1,240
	„	4 09 p.m.	„ Iwaki.	90	60	—	60	1,500	1,560
Feb.	24	8 32 p.m.	Off Kinkazan (Rikuzen).	180	100	10	1,850	3,570	5,430
	26	5 50 p.m.	Tokyo Bay.	80	70	40	790	2,020	2,850

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shroter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904			*ri*	*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*
March 7	7^h37^m a.m.	S. part of Yamato.	50	40	100	270	180	550
8	3 40 a.m.	Off the coast of Hitachi.	220	120	490	2,010	4,200	6,700
„	11 29 p.m.	Do.	70	60	—	230	1,020	1,250
12	6 12 a.m.	Vicinity of Kasumiga-ura.	100	60	—	200	900	1,100
18	5 33 a.m.	Off the W. coast of Kii.	130	90	290	1,120	3,220	4,630
„	10 44 p.m.	„ SE. coast of Nemuro.	400	200	870	2,850	7,500	11,220
25	2 56 a.m.	„ E. coast of Rikuzen.	120	50	—	180	1,040	1,220
26	8 20 a.m.	SW. part of Ise.	40	25	—	310	420	730
27	1 32 p.m.	Off the E. coast of Mutsu.	110	70	—	240	1,330	1,570
28	6 28 p.m.	Boundary between Iwaki and Rikuzen.	40	30	—	210	290	500
April 4	8 20 a.m.	Vicinity of Kasumiga-ura.	70	60	—	170	1,620	1,790
13	2 38 p.m.	Off the coast of Rikuzen.	160	60	—	380	4,250	4,550
18	7 51 p.m.	Do.	60	50	—	30	590	620
„	8 03 p.m.	Uraga channel.	80	70	—	640	2,540	3,180
19	1 21 p.m.	Off the coast of Kushiro.	250	160	—	100	1,420	1,520
23	4 51 a.m.	Off the E. coast of Rikuzen.	180	80	—	1,870	4,740	6,610
24	8 08 a.m.	Outside the Rikuzen Bay.	270	140	750	2,280	3,930	6,960
„	3 38 p.m.	Toroku, Kagi, Ensuiko, Tainan, and Banshoryo (Formosa) $\varphi=23^\circ\ 30'N,\ \lambda=120^\circ\ 26'E$	160	80	360	1,270	630	2,260
27	3 14 a.m.	Vicinity of Tsukuba-San.	40	30	—	160	610	770
May 8	4 23 a.m.	Muikamachi (Echigo). $\varphi=36^\circ\ 53'N,\ \lambda=138^\circ\ 48'E$	230	140	1,080	4,770	5,860	11,710
„	7 24 a.m.	Sahara (Shimosa).	60	40	—	60	1,310	1,370
„	8 00 a.m.	Muikamachi (Echigo).	80	50	—	400	2,360	2,760
16	2 24 p.m.	N. part of Suruga.	60	50	—	700	1,050	1,750
17	4 03 p.m.	Bay of Chiba (Tokyo Bay).	80	50	—	170	1,750	1,920
20	5 35 p.m.	Sea of Aki.	220	180	760	3,030	6,480	10,270

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1904				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
May	21	5^h25^m a.m.	Off the E. coast of Mutsu.	120	100	—	430	1,920	2,350
	23	3 31 a.m.	„ coast of Harima.	110	90	330	960	4,130	5,420
	27	5 41 a.m.	Uraga channel.	70	60	—	140	1,310	1,45.
	„	7 46 a.m.	Tokyo Bay.	50	40	—	70	880	950
June	6	3 41 a.m.	Vicinity of Shishido Lake, Izumo.	150	130	570	1,890	4,030	6,490
	„	11 51 a.m.	Do.	180	100	460	2,370	6,290	9,120
	7	5 19 p.m.	Off the coast of Iwaki. $\varphi=38°N$, $\lambda=144° 15'E$.	450	300	90	5,850	14,650	20,590
	14	10 39 a.m.	Off the coast of Rikuzen.	150	130	—	310	5,570	5,880
	15	2 17 a.m.	S. part of Rikuzen.	70	40	—	120	850	970
	22	11 26 a.m.	Off Kinkazan (Rikuzen).	140	80	10	510	2,770	3,290
	24	3 44 a.m.	Vicinity of Lake Suwa (Shinano).	70	35	—	270	1,050	1,320
	30	8 21 a.m.	Sahara (Shimosa).	70	35	60	320	790	1,170
	„	8 23 a.m.	Do.	40	30	40	250	370	660
July	1	10 29 p.m.	Off the SE. coast of Nemuro.	350	300	250	2,300	5,250	7,800
	8	0 02 p.m.	Neo-Valley (Mino).	40	20	—	130	390	520
	12	7 40 p.m.	Off the E. coast of Kazusa.	200	180	—	160	5,440	5,600
	13	4 13 p.m.	„ Mutsu.	180	150	—	920	2,330	3,250
	15	3 44 a.m.	„ Kazusa.	130	80	—	460	1,630	2 090
	„	3 53 a.m.	Do.	70	40	—	170	420	590
	16	10 09 a.m.	Do.	200	150	180	380	4,300	5,310
	„	10 34 a.m.	Do.	70	40	—	310	620	930
	17	4 27 a.m.	Do.	100	60	—	860	1,360	2 320
	18	7 51 p.m.	Do.	80	60	40	250	1,170	1,460
	19	6 20 p.m.	Do.	140	70	80	270	2,250	2,600
	20	0 30 p.m.	Do.	140	130	70	550	4,530	5,150

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
July	26	9^h01^m p.m.	Bay of Iburi.	150	70	—	420	2,590	3,010
Aug.	4	9 49 p.m.	N. part of Shimosa. $\varphi=35°\ 43'$ N, $\lambda=139°54'$ E.	150	90	320	1,250	1,840	3,410
	7	5 25 a.m.	Outside the Rikuzen Bay.	210	90	10	690	3,000	3,700
	15	10 30 p.m.	,,	160	80	210	1,050	1,560	2,820
	21	6 49 a.m.	Off the E. coast of Kunajiri-shima.	250	200	—	100	800	900
	22	10 03 p.m.	Off the SE. coast of Nemuro.	350	200	—	1,160	2,380	3,540
	25	6 01 a.m.	Off the Island of Oshima. (Lyu Kyu)	400	250	20	1,340	2,910	4,270
	26	9 22 a.m.	Tsugaru Strait.	120	80	—	90	340	430
	29	2 39 p.m.	Vicinity of Kameyama (Tanba).	70	40	—	360	730	1,090
Sept.	4	9 53 p.m.	Central part of Kii.	35	25	—	210	410	620
	7	1 50 p.m.	Taichu (Formosa).	130	80	—	260	740	1,000
	14	2 59 a.m.	Off the coast of Tokachi.	100	70	—	150	960	1,110
	20	4 18 a.m.	Bay of Chichiiwa (Hizen).	50	30	—	90	180	270
	21	2 51 p.m.	Off the coast of Iyo.	180	130	760	3,260	2,650	6,670
	25	10 35 a.m.	Tsugaru strait.	180	100	—	810	2,350	3,160
Oct.	5	0 35 a.m.	N. part of Shimosa.	70	30	—	130	1,700	1,830
	7	11 12 a.m.	Off the E. coast of Kii.	60	30	60	350	660	1,070
	13	7 23 p.m.	,, coast of Iwaki.	60	30	—	160	1,350	1,510
	20	2 01 a.m.	S. part of Mikawa.	70	50	—	380	560	940
	,,	6 28 p.m.	Off the coast of Hidaka.	220	100	—	490	2,120	2,610
	25	0 28 a.m.	,, Iwaki.	180	70	110	430	1,840	3,380
	27	6 24 a.m.	,, Shimosa.	90	70	—	90	380	470
	28	7 11 a.m.	,, Hitachi.	180	150	—	120	5,220	5,340

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1904			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Nov. 3	$5^h 40^m$ p.m.	Outside the Rikuzen Bay.	110	70	—	210	900	1,110
4	1 45 p.m.	Off Kinkazan (Rikuzen).	120	80	10	200	430	6,400
6	6 25 a.m.	Kagi, Toroku, and Ensuiko (Formosa). $\varphi=23°30'$N, $\lambda=120°26'$E.	?	?	520	800	790	2,110
7	4 20 p.m.	Boundary between Mikawa and Mino.	60	40	—	170	460	630
11	0 10 a.m.	Kashiwabara (Tango).	50	40	—	160	730	890
13	9 49 a.m.	Vicinity of Ogasawara-jima.	—	—	—	10	580	590
Dec. 16	5 23 p.m.	Off the coast of Shimosa.	80	50	—	100	240	340
17	9 40 a.m.	Do.	140	80	—	210	1,070	1,280
,,	4 03 p.m.	Off the E. coast of Mutsu.	250	150	530	3,790	3,060	6,850
22	7 39 p.m.	Vicinity of Kumamoto (Higo).	70	60	60	580	810	1,450
23	9 56 a.m.	Off the coast of Shimosa.	130	90	—	230	400	630
24	11 47 a.m.	,, Rikuzen.	280	160	640	2,280	2,950	5,870
1905								
Jan. 2	4 26 p.m.	N. part of Rikuzen.	80	50	—	80	1,340	1,420
,,	11 55 p.m.	Off the coast of Taito (Formosa)	160	120	—	240	660	900
11	7 15 a.m.	S. part of Formosa.	90	?	—	360	340	700
23	8 31 a.m.	Off the W. coast of Sado.	70	60	—	50	730	780
25	11 12 a.m.	Boundary between Chikugo and Higo.	60	50	110	380	1,490	1,980
26	4 02 p.m.	Off the coast of Hitachi.	100	70	—	510	1,550	2,060
28	9 57 p.m.	S. part of Hyuga.	70	50	110	490	730	1,330
Feb. 2	8 15 a.m.	Off Cape Erimo (Hidaka).	230	120	—	270	850	1,120
,,	9 08 a.m.	Outside the Rikuzen Bay.	90	50	—	10	340	350
5	3 41 a.m.	Vicinity of Lake Biwa.	?	130	490	2,470	1,740	4,700
7	11 23 a.m.	Outside the Rikuzen Bay.	80	50	—	70	230	300

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1905			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Feb. 7	$0^h 33^m$ p.m.	SE. part of Mino.	60	25	—	120	280	400
„	2 47 p.m.	Off the coast of Iwaki.	130	70	—	140	990	1,130
11	7 06 a.m.	Do.	90	60	—	60	760	820
14	10 55 p.m.	Do.	110	60	—	40	930	970
17	3 27 a.m.	Outside the Rikuzen Bay.	120	50	—	10	1,080	1.090
„	6 44 p.m.	Off the coast of Iwaki.	130	80	190	660	1,160	2,010
21	2 24 p.m.	„ Cape Erimo (Hidaka).	280	150	—	500	3,150	3,650
26	8 45 p.m.	„ the E. coast of Mutsu.	200	120	—	510	1,390	1,900
27	1 19 a.m.	Off Chōshi (Shimosa).	80	40	—	30	260	290
28	11 01 p.m.	Bay of Wakasa.	90	60	—	230	880	1,110
March 4	9 18 p.m.	Bay of Chiba (Tokyo Bay).	110	60	—	400	720	1,120
6	6 08 a.m.	Uraga Channel.	70	40	—	210	800	1,010
„	10 32 a.m.	Off the coast of Rikuzen.	110	70	—	140	360	500
13	0 46 p.m.	„ Hyuga.	80	60	—	30	410	470
16	11 54 p.m.	Bungo Strait.	120	60	40	540	940	1,520
18	4 40 a.m.	Bay of Toyama (Etchu).	130	100	20	860	1,180	2,060
April 6	11 10 a.m.	Off the SE. coast of Kunashiri.	150	80	10	200	680	890
„	9 30 p.m.	E. part of Musashi.	80	50	—	940	1,770	2,710
10	10 04 p.m.	Off the coast of Taitō (Formosa).	100	80	—	650	1,500	2,150
13	6 02 p.m.	Vicinity of Yokohama.	140	60	150	420	470	1,040
16	8 05 a.m.	Off Cape Shiriya (Mutsu).	150	120	190	850	1,000	2.040
18	0 21 a.m.	Sea of Aki.	60	20	50	260	830	1,140
24	5 15 a.m.	S. part of Musashi.	130	60	—	770	790	1,560
May 9	2 54 a.m.	Off the coast of Hitachi.	200	140	—	170	1,200	1,370

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1905				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
May	17	2^h04^m a.m.	Off the coast of Hidaka.	180	100	190	770	1,090	2,050
	26	3 46 p.m.	„ Iwaki.	150	70	70	310	1,450	1,830
	30	4 32 a.m.	Kanagawa (Musashi).	60	20	—	40	90	130
	31	11 08 a.m.	Off the coast of Hidaka.	120	60	—	130	430	560
June	2	2 40 p.m.	Central part of Inland Sea.	450	200	4,750	3,950	2.200	10,900
	„	7 56 p.m.	Do.	230	140	120	3,590	4,960	8,470
	3	9 18 a.m.	Do.	110	60	—	970	3,990	4.960
	„	9 34 a.m.	Do.	180	90	280	2,870	3,200	6,350
	„	7 24 p.m.	Do.	100	50	—	1,040	2,990	4,030
	„	7 38 p.m.	Do.	180	70	200	1,800	2,500	4.500
	„	10 49 p.m.	Do.	120	60	—	860	2.490	3,350
	4	3 08 a.m.	Do.	90	50	—	590	1.720	2,310
	5	8 44 a.m.	Vicinity of O-shima (Izu).	60	50	10	150	200	360
	6	0 44 a.m.	Do.	90	70	—	190	420	610
	„	1 19 a.m.	Do.	60	40	—	380	260	640
	„	1 51 a.m.	Do.	100	70	—	460	430	890
	„	2 05 a.m.	Do.	70	60	—	510	210	720
	„	2 23 a.m.	Do.	90	70	—	550	290	810
	„	5 17 a.m.	Do.	90	60	—	320	100	420
	„	9 23 a.m.	Do.	90	60	—	300	230	530
	„	11 47 a.m.	Do.	60	40	—	160	170	330
	„	8 32 p.m.	Central part of Inland Sea.	80	40	—	570	1,230	1,800
	7	6 12 a.m.	Vicinity of Edosaki (Hitachi).	40	30	—	70	690	760
	„	2 40 p.m.	Vicinity of O-shima (Izu).	220	120	510	740	2,220	3,470
	„	10 06 p.m.	Do.	110	70	150	280	390	820
	10	3 10 p.m.	Do.	150	100	—	270	440	710

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1905			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
June 11	11h52m p.m.	N. part of Shimosa.	70	40	—	380	540	920
12	5 17 p.m.	Off the coast of Iwaki.	250	130	750	1,620	2,450	4,820
13	2 49 p.m.	Off Kinkazan (Rikuzen).	80	70	—	510	730	1,240
18	1 17 a.m.	Off the coast of Iwaki.	140	90	—	210	1,620	1,830
20	0 36 p.m.	" Nemuro.	300	100	—	110	1,420	1,530
21	6 45 p.m.	N. part of Mino.	90	40	—	370	1,220	1,590
27	1 13 a.m.	Central part of Rikuchū.	220	70	—	1,890	1,130	3,020
July 1	1 49 a.m.	Vicinity of Mishima (Nagato).	90	50	—	220	600	820
"	9 06 a.m.	Ayabe (Tanba).	60	50	20	600	630	1,250
7	1 22 a.m.	Off the coast of Iwaki.	300	200	1,400	4,380	2,280	8,060
"	7 18 a.m.	Do.	300	180	—	440	4,840	5,280
"	10 19 a.m.	Off the coast of Tokachi.	240	160	—	140	4,700	4,840
9	7 13 a.m.	" Iwaki.	230	140	30	1,670	2,930	4,630
13	1 49 p.m.	" E. coast of Mutsu.	270	150	—	420	3,180	3,600
16	6 49 p.m.	" coast of Ugo.	120	100	—	400	1,130	1,530
19	5 03 p.m.	Bay of Tokyo.	80	50	—	60	560	620
21	6 16 p.m.	Off Kinkazan (Rikuzen).	110	80	—	510	570	1,080
23	5 26 p.m.	Town of Yasuzuka, Higashi-Kubiki county (Echigo).	140	100	110	770	2,330	3,210
"	6 27 p.m.	Do.	110	60	10	100	830	940
"	7 01 p.m.	Off Kinkazan (Rikuzen).	150	80	—	170	1,370	1,540
27	1 39 a.m.	S. part of Shimotsuke.	90	40	—	140	1,150	1,290
Aug. 5	2 29 p.m.	SE. part of Hida.	90	40	—	290	610	900
12	9 28 p.m.	Bay of Tokyo.	60	30	—	70	400	470
18	6 08 a.m.	Bay of Atsumi (Mikawa).	90	40	—	270	350	620
22	11 32 p.m.	Off the E. coast of Rikuzen.	110	60	—	260	440	700

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1905			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Aug. 24	0^h05^m p.m.	Off the coast of Hitachi.	100	50	—	490	940	1,430
„	6 11 p.m.	Hagiwara, Masuda county (Hida).	110	40	40	230	500	770
26	5 16 p.m.	Off Cape Muroto (Tosa).	140	70	160	880	1,400	2,440
29	1 28 p.m.	Off the SE. coast of Kushiro.	250	150	—	400	670	1,070
30	9 27 a.m.	„ Omae-zaki (Totomi).	90	50	—	60	620	680
Sept. 1	11 47 a.m.	Off the E. coast of Mutsu.	300	200	240	3,720	2,240	6,200
„	2 52 p.m.	„ coast of Totomi.	60	50	—	260	180	440
2	0 52 a.m.	Tono-machi (Rikuchu).	150	70	—	530	820	1,350
„	3 48 p.m.	Off the coast of Rikuzen.	200	100	—	440	870	1,290
3	2 02 a.m.	Uraga channel.	120	70	160	550	1,240	1,950
6	5 11 p.m.	Off the E. coast of Kii.	70	45	80	290	210	580
8	11 06 a.m.	Boundary between Hōki and Izumo.	40	25	—	170	330	500
9	3 01 p.m.	S. part of Kii.	80	50	110	490	250	850
12	0 52 p.m.	Central part of Inland Sea.	170	90	470	3,180	2,500	6,150
21	10 00 p.m.	Vicinity of Chiba (Shimosa).	150	110	—	980	1,420	2,400
24	2 08 a.m.	Boundary between Hitachi and Shimosa.	70	40	—	180	480	660
29	10 19 a.m.	Boundary between Mino and Echizen.	140	80	—	1,100	1,850	2 950
30	11 31 p.m.	Off the E. coast of Mutsu.	120	70	—	50	1,000	1,050
Oct. 2	10 54 a.m.	Off the coast of Hitachi.	200	150	120	2,830	2,080	5,030
3	6 18 p.m.	Boundary between Hida and Kaga.	110	40	—	160	600	760
4	8 15 a.m.	Off Cape Shiriya (Mutsu).	270	180	350	3,950	2,700	7,000
7	9 53 p.m.	Off the E. coast of Mutsu.	120	90	—	180	640	820
10	10 54 a.m.	Off Chōshi (Shimosa).	170	140	—	660	1,100	1,760
13	3 14 p.m.	Off Cape Kamui (Shiribeshi).	120	100	50	490	990	1,530
14	11 54 a.m.	Bay of Chiba (Tokyo Bay).	160	60	40	560	850	1,450

(1) Date.		(2) Time of occurrence.		(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
					(4) Longer axis	(5) Shorter axis	(6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1905					*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Oct.	16	1h52m	a.m.	SE. part of Hida.	90	50	—	200	1,210	1,410
	19	1 42	a.m.	Central part of Mino.	80	50	—	290	440	730
	„	9 10	a.m.	E. part of Musashi.	130	50	—	470	930	1,400
	24	0 48	p.m.	Off the E. coast of Awa peninsula.	220	120	—	250	1,020	1,270
	28	6 45	p.m.	Off the SE. coast of Kushiro.	250	100	—	300	550	850
Nov.	1	2 00	p.m.	Off the coast of Iwaki.	140	80	—	360	1,530	1,890
	2	11 21	a.m.	„ Kazusa.	160	120	—	620	1,260	1,880
	9	7 19	p.m.	W. part of Echigo.	140	120	—	710	1,150	1,860
	22	9 43	a.m.	Off the E. coast of Formosa.	160	?	—	1,660	780	2,440
	23	0 01	a.m.	Off the coast of Rikuchū.	200	100	—	460	830	1,290
Dec.	2	6 32	a.m.	Ariake Sea (Higo).	200	150	110	1,180	750	2,040
	3	1 46	p.m.	Off Kinkazan (Rikuzen).	180	130	10	1,110	2,260	3,380
	5	1 18	a.m.	Do.	150	80	10	270	900	1,180
	„	4 38	a.m.	Outside the Iburi Bay.	160	80	—	80	800	880
	8	0 08	p.m.	Central part of Inland Sea.	240	160	770	4,130	3,340	8,240
	„	1 26	p.m.	Do.	220	160	380	4,850	3,390	8,620
	17	6 29	p.m.	Off the coast of Nagato.	80	70	—	120	1,590	1,710
	23	11 37	a.m.	„ Rikuchū.	250	170	760	2,310	2,360	5,430
	26	0 11	p.m.	Off the coast of Hitachi.	220	160	920	2,680	2,220	5,820
	27	0 51	p.m.	Kaita-mura, Nishi-Chikuma county, Shinano.	160	50	20	400	1,140	1,560
	30	7 53	p.m.	Bay of Chiba (Tokyo Bay).	50	40	—	70	200	270
1906										
Jan.	1	6 18	a.m.	Sea of Ise.	80	50	—	730	710	1,440
	5	6 06	a.m.	Bay of Osaka.	30	20	—	120	440	560
	„	6 01	p.m.	Do.	40	30	—	400	500	900

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1906			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Jan. 6	4^h28^m a.m.	Off the E. coast of Mutsu.	110	90	—	530	860	1,390
„	0 48 p.m.	„ Rikuchu.	70	50	—	260	310	570
7	8 52 p.m.	Bay of Osaka.	90	60	—	700	810	1,510
8	11 00 p.m.	Off the coast of Sagami.	180	120	20	830	840	1,690
9	6 50 p.m.	Central part of Shimosa.	70	40	—	220	690	910
„	9 55 p.m.	Bay of Chiba (Tokyo Bay).	60	40	—	20	320	340
12	10 23 a.m.	Off the E. coast of Kii.	130	90	200	900	790	1,890
15	7 54 a.m.	N. part of Sagami.	40	30	—	100	340	440
18	9 20 p.m.	N. part of Mino.	140	80	170	1,420	1,640	3,230
21	10 50 p.m.	Off the E. coast of Main Island $\varphi=34°\ 23'$ N, $\lambda=143°\ 26'$E.	400	350	1,640	5,260	7,570	14,470
24	5 07 a.m.	Off the coast of Iwami.	150	50	—	280	1,110	1,390
Feb. 4	3 24 p.m.	Rikuzen Bay.	220	130	90	2,150	2,230	4,470
5	3 11 a.m.	Outside the Rikuzen Bay.	150	60	—	240	1,030	1,270
„	5 09 a.m.	Rikuzen Bay.	200	120	—	880	2,200	3,080
17	6 41 a.m.	Off the E. coast of Kazusa.	340	140	50	400	530	980
18	2 15 p.m.	S. part of Kazusa.	140	110	—	270	690	960
23	6 49 p.m.	Off the coast of Awa and Kazusa peninsula.	300	200	290	1,900	3,500	5,690
24	9 14 a.m.	Tokyo Bay.	350	200	840	4,190	5,070	10,100
28	0 10 a.m.	S. part of Ise.	70	40	—	230	700	930
March 6	1 38 a.m.	Off the coast of Awa and Kazusa.	250	200	—	120	190	310
7	11 17 a.m.	Off the coast of Iwaki.	250	150	—	380	2,980	3,360
8	4 08 a.m.	Boundary between Mino and Owari.	90	60	—	190	740	930
13	10 29 p.m.	Off the coast of Hyūga.	200	150	910	2,160	2,700	5,770
14	1 11 a.m.	Do.	70	60	—	40	80	120
„	8 32 p.m.	Off the coast of Kazusa.	100	80	—	450	1,080	1,530

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
March 16	0h05m a.m.	Central part of Inland Sea.	100	50	—	100	3,100	3,200
17	8 43 a.m.	Kagi (Formosa).	500	?	970	1,310	—	2,280
„	9 21 p.m.	Northern part of Ariake Sea, (Kyushu).	50	30	—	90	810	900
„	9 23 p.m.	Do.	200	120	250	2,150	1,200	3,600
18	0 12 a.m.	Do.	60	30	—	80	230	310
„	1 10 a.m.	S. part of Kii.	170	110	160	1,080	2,330	3,570
„	5 32 a.m.	Northern part of Ariake Sea (Kyushu).	40	20	—	60	630	690
„	6 30 a.m.	Off the coast of Hyūga.	150	100	—	150	2,290	2,440
21	11 43 p.m.	„ „ Rikuzen.	170	100	—	190	790	980
23	5 40 a.m.	„ E. coast of Mutsu.	200	150	—	210	560	770
24	9 59 a.m.	Near O-shima (Lyu-kyu).	150	—	—	80	20	100
26	1 29 p.m.	Kagi (Formosa).	100	80	200	1,090	940	2,230
28	8 57 a.m.	Do.	80	70	100	520	1,580	2,200
29	6 14 a.m.	Do.	100	80	200	920	420	1,540
April 4	10 04 a.m.	Off the coast of Rikuzen.	130	70	—	340	820	1,160
5	11 50 a.m.	„ Iwaki.	240	180	190	2,370	3,090	5,650
6	4 58 a.m.	Kagi (Formosa).	100	80	70	650	940	1,660
„	7 29 p.m.	Off the E. coast of Nemuro.	350	?	20	400	470	890
7	2 52.7 p.m.	Tenshiko (Formosa).	—	100	270	970	970	2,210
8	8 39.7 a.m.	Kagi „	100	80	100	920	1,120	2,140
„	2 52 p.m.	Off the E. coast of Awa peninsula.	160	70	—	680	1,620	2,300
9	2 38 a.m.	Off the coast of Iwaki.	230	160	—	360	3,890	4,250
11	7 08 p.m.	NW. part of Mino.	140	90	90	1,530	1,770	3,390
14	5 18 a.m.	Tenshiko (Kagi Prefecture) Formosa.	—	—	2,060	220	—	2,280
„	9 52 a.m.	Do.	—	—	740	1,240	300	2,280
20	9 48 p.m.	Hagiwara, Masuda county (Hida).	90	70	60	310	1,850	2,220

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1906				ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
April	21	4h40m a.m.	Hagiwara, Masuda county (Hida).	?	210	580	3,320	3,310	7,210
„		3 54 p.m.	Kosaka, Masuda county (Hida).	110	60	40	210	820	1,070
May	1	7 12 p.m.	Bungo Strait.	80	60	—	290	1,360	1,650
	2	11 13 a.m.	Off the N. coast of Formosa.	150	?	—	450	2,000	2,450
	5	8 09 a.m.	„ S. coast of Kii.	450	200	1,160	2,160	6,330	9,650
	„	8 53 a.m.	Central part of Kii.	90	60	100	700	1,030	1,830
	6	10 20 p.m.	NW. part of Higo.	60	35	10	170	470	650
	7	8 01 a.m.	Off the E. coast of Awa peninsula.	120	70	—	120	410	530
	10	2 34 p.m.	Vicinity of Kawawa (Musashi).	80	40	—	40	250	290
	16	7 10 p.m.	Off the coast of Hitachi.	170	140	—	30	1,700	1,730
	18	4 04 p.m.	„ Iwaki.	120	90	—	390	1,600	1,990
	„	9 36 p.m.	„ Shimosa.	110	70	—	40	230	270
	19	1 31 a.m.	Do.	220	180	170	670	2,980	3,820
	21	2 21 p.m.	Tokyo Bay.	120	60	—	380	430	810
	„	3 56 p.m.	N. part of Shimosa.	150	80	250	1,710	1,430	3,390
	22	4 12 p.m.	Central part of Inland Sea.	150	120	650	1,570	2,220	4,440
	24	2 17 p.m.	Uraga channel.	45	30	—	60	210	270
	28	4 10 a.m.	Off the E. coast of Nemuro.	300	200	60	580	1,300	1,940
	„	6 59 a.m.	„ coast of Kazusa.	140	90	—	350	470	820
	29	11 22 p.m.	N. part of Shimosa.	130	70	120	1,080	1,060	2,260
	30	9 27 p.m.	Tokyo Bay.	60	35	—	190	500	690
June	2	7 18 a.m.	Vicinity of Naruto, Awa.	80	60	170	850	890	1,910
	10	10 37 a.m.	Off Kinkazan (Rikuzen).	80	60	—	10	320	330
	22	2 28 a.m.	Uyeda (Shinano).	60	50	40	400	560	1,000
July	7	7 30 p.m.	Outside the Rikuzen Bay.	180	90	—	170	1,490	1,660

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
July 7	$8^h 41^m$ p.m.	Off Kinkazan (Rikuzen).	130	70	—	90	310	400
10	9 37 a.m.	Off the coast of Iwaki.	90	70	—	120	330	450
11	5 32 a.m.	Central part of Mikawa.	50	30	—	100	610	710
12	4 31 p.m.	Off the coast of Hitachi.	160	100	—	170	640	810
23	1 18 p.m.	„ Iwaki.	180	140	280	1,880	2,770	4,930
31	8 58 p.m.	„ Rikuchū.	90	70	—	160	520	680
Aug. 5	4 53 a.m.	Tokyo Bay.	70	60	—	440	770	1,210
„	5 32 a.m.	Do.	120	50	210	860	1,350	2,420
9	9 15 p.m.	Off the coast of Hyuga.	130	80	—	140	450	590
„	10 27 p.m.	Do.	200	100	—	1,050	1,030	2,080
16	6 26 a.m.	Central part of Izu.	90	70	—	190	430	620
„	3 39 p.m.	Do.	100	80	50	80	930	1,060
19	8 00 a.m.	Off Chōshi (Shimosa).	180	120	10	730	2,940	3,680
21	5 42 a.m.	W. part of Kazusa.	140	50	—	80	290	370
22	0 08 a.m.	W. part of Shimosa.	120	50	100	810	920	1,830
31	11 20 a.m.	Central part of Izu.	140	80	10	350	920	1,280
Sept. 4	9 46 a.m.	Town of Mifune, (Higo).	60	45	—	160	110	270
8	3 53 a.m.	Off the E coast of Awa and Kazusa.	170	90	—	130	770	900
15	0 34 a.m.	Vicinity of Matsuzaka (Ise).	60	30	—	50	100	150
17	5 27 p.m.	W. part of Hitachi.	130	110	—	680	1,940	2,620
19	7 55 p.m.	Central part of Izu.	60	40	—	60	490	550
Oct. 4	0 05 a.m.	Off the coast of Rikuzen.	120	60	—	230	370	600
6	6 35 p.m.	N. part of Shimosa.	120	50	—	550	1,700	2,250
„	8 52 p.m.	Near the coast of Iwaki.	150	100	—	1.210	2,210	3,420

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) *Strong* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1906			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Oct. 6	9^h24^m p.m.	Central part of Shimotsuke.	110	50	—	120	1,610	1,730
10	9 51 p.m.	SW. part of Iwaki.	140	80	—	1,200	1,650	2,850
12	9 56 a.m.	Off the coast of Ugo.	180	140	200	2,180	1,810	4,190
,,	10 04 a.m.	Do.	220	140	590	1,570	1,950	4,110
19	9 29 p.m.	Off the coast of Awa and Kazusa.	100	70	—	160	360	520
,,	10 46 p.m.	Bungo Strait.	70	40	—	530	1,040	1,570
23	7 13 a.m.	N. shore of Lake Biwa.	35	30	—	140	290	430
26	5 25 p.m.	S. part of Yamato.	90	50	—	380	340	720
27	7 25 a.m.	Off the coast of Iwaki.	300	200	—	320	3,550	3,870
Nov. 7	11 54 p.m.	,, Sagami.	70	50	—	150	350	500
9	6 54 p.m.	,, Iwaki.	120	50	—	140	540	680
11	0 33 a.m.	,, Awa peninsula.	50	30	—	20	80	100
12	11 07 p.m.	Vicinity of Kasumiga-ura.	150	80	60	1,370	1,610	3,040
15	7 24 p.m.	N. part of Hyuga.	50	40	—	360	520	880
16	1 54 a.m.	W. part of Owari.	40	20	—	90	140	230
22	6 44 a.m.	Central part of Bingo.	50	30	—	140	490	630
23	3 32 p.m.	Off the coast of the Awa peninsula.	180	100	30	670	630	1,330
24	4 40 a.m.	Off Kinkazan (Rikuzen).	110	60	—	10	570	580
,,	5 45 p.m.	Do.	90	60	—	10	580	590
Dec. 2	0 33 p.m.	Vicinity of Ueda (Shinano).	60	30	—	100	230	330
4	8 44 p.m.	Off the coast of Hitachi.	90	50	—	160	830	990
5	5 54 p.m.	Central part of Kii.	50	40	—	330	330	660
10	7 52 a.m.	Tosa Bay.	100	80	20	230	820	1,070
24	5 46 p.m.	Katori county (Shimosa).	80	60	—	90	250	340
27	9 05 p.m.	Vicinity of Ueda (Shinano).	70	30	—	80	180	260

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1907			*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
June 11	8^h59^m a.m.	Off the NE. coast of Kazusa. $\varphi=35°\ 30'N$, $\lambda=140°\ 45'E$.	250	180	160	2,140	2,480	4,780
14	1 43 p.m.	"	150	130	40	300	810	1,150
29	2 50 p.m.	Vicinity of Suzaka (Shinano).	80	70	30	250	470	750
July 1	11 48 a.m.	Off the coast of Hitachi.	130	80	—	220	920	1,140
2	5 45 a.m.	Vicinity of Kasumiga-ura.	120	100	—	250	930	1,180
4	9 17 p.m.	Off the N. coast of Formosa.	200	—	—	200	750	950
6	0 45 a.m.	" Nemuro.	400	200	900	4,150	5,400	10,450
16	6 35 a.m.	Do.	60	40	—	270	550	820
24	1 16 a.m.	Off the coast of Kushiro.	80	70	—	350	620	970
26	8 10 p.m.	Off the E. coast of Mutsu.	110	60	—	250	510	760
27	4 23 p.m.	Vicinity of Kawawa (Musashi)	150	100	100	650	500	1,250
Aug. 1	3 47 p.m.	Central part of Formosa.	40	30	50	230	500	780
7	11 47 a.m.	Bungo Strait.	100	60	100	780	1,230	2,110
14	4 50 a.m.	Off the coast of Ugo.	170	140	170	1,560	2,460	4,190
26	8 54 a.m.	E. part of Izumo.	230	160	290	2,650	2,150	5,090
28	3 57 p.m.	Do.	70	40	—	210	560	770
31	4 04 p.m.	Off Kinkazan (Rikuzen).	130	80	—	120	530	650
Sept. 1	8 08 a.m.	Near Koshiki-jima, off the S. coast of Kyushu.	100	60	70	320	660	1,050
8	2 10 a.m.	Off the coast of Hidaka.	130	80	—	30	380	410
13	7 27 p.m.	E. part of Izumo.	70	35	—	430	480	910
15	6 01 p.m.	Off the coast of Hidaka.	230	150	110	1,200	1,600	2,910
"	8 21 p.m.	Off the coast of Hidaka.	250	150	170	1,120	3,150	4,440
16	2 21 a.m.	E. part. of Izumo.	50	25	—	190	230	420

(1) Date.		(2) Time of occurrence.	(3) Origin of disturbance.	Total area of disturbance.		Area of sensible motion.			
				(4) Longer axis	(5) Shorter axis	(6) *Slight* motion	(7) *Moderate* motion	(8) *Slight* motion	(9) *Sum*
1907				*ri*	*ri*	sq. *ri*	sq. *ri*	sq. *ri*	sq. *ri*
Sept.	22	4 50 a.m.	Off the E. coast of Kazusa.	230	180	580	930	1,010	2,520
"		9 08 p.m.	Off the S. end of Formosa.	150	—	—	20	300	320
Oct.	1	6 16 p.m.	Tokyo Bay.	80	40	—	40	260	300
	5	5 28 a.m.	Some distance off the coast of Iwaki.	300	200	—	1,380	4,130	5,510
	10	8 13 p.m.	In Lake Biwa.	40	20	—	90	180	270
	11	3 51 a.m.	Off the coast of Echizen.	120	100	30	1,110	2,040	3,180
	13	1 40 p.m.	Near the coast of Sagami.	60	30	10	140	210	360
	15	9 05 a.m.	Off the coast of Hitachi.	250	150	190	2,160	2,120	4,470
	24	5 14 a.m.	Near E. coast of Kii.	70	60	170	400	510	1,080
	27	3 46 p.m.	S. part of Hida.	140	100	210	1,490	2,400	4,100
	28	8 33 a.m.	Off the coast of Iwami.	100	50	—	300	590	890
	"	5 54 p.m.	Do.	80	60	—	370	1,250	1,620
	"	9 17 p.m.	Off the coast of Iwaki.	200	180	160	2,410	2,840	5,410
Nov.	4	6 03 a.m.	Near Koshiki-shima, off the S. coast of Kyushu.	70	60	—	70	410	480
	10	2 03 a.m.	Vicinity of Kawawa (Musashi)	50	40	—	30	170	200
	11	7 44 a.m.	Off the NE. coast of Rikuzen.	100	60	—	20	230	250
	13	11 11 a.m.	Off Cape Shiriya (Mutsu).	150	80	—	180	490	670
	21	1 32 p.m.	Tokyo Bay.	70	40	—	60	790	850
	22	2 17 a.m.	N. part of Musashi. $\varphi=36° 15' N$, $\lambda=139° 45' E$	200	120	1,420	2,310	2,830	6,560
	27	6 36 p.m.	Off cape Shiriya (Mutsu).	250	150	170	1,880	3,670	5,720
	28	11 28 a.m.	N. part of Shimosa.	35	20	—	70	490	560
	29	5 21 a.m.	Off the NE. coats of Rikuzen.	70	40	—	60	90	150
Dec.	2	10 53 p.m.	" E. coast of Mutsu.	300	200	2,020	2,220	2,920	7,160
	3	8 23 a.m.	Formosa.	200	150	—	100	770	870

(1) Date.	(2) Time of occurrence.	(3) Origin of disturbance.	Total Area of disturbance. (4) Longer axis	(5) Shorter axis	Area of sensible motion. (6) Strong motion	(7) Moderate motion	(8) Slight motion	(9) Sum
1907			ri	ri	sq. ri	sq. ri	sq. ri	sq. ri
Dec. 10	0 39 a.m.	Vicinity of Iwamurata (Shinano).	60	20	—	100	290	390
11	5 54 p.m.	Vicinity of Chiba, Shimosa.	120	60	—	340	570	910
15	6 09 a.m.	Sea of Amakusa (Kyushu).	120	70	—	20	330	350
20	8 42 p.m.	Off the E. coast of Mutsu.	130	100	—	330	1,330	1,660
23	10 14 a.m.	„ coast of Kushiro.	450	250	950	2,300	2,820	6,070

明治四十一年三月廿五日印刷
明治四十一年三月廿八日發行

編纂兼發行者　震災豫防調査會

東京市神田區美土代町二丁目一番地
印刷者　島連太郎

東京市神田區美土代町二丁目一番地
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On the Fore-shocks of Earthquakes.

By

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With Pl. XXIII.

CONTENTS.

1. ***Introduction.*** It often happens that precursory shakings, or "fore-shocks," of different intensities are felt at the epicentral district of a great earthquake. As the latter is generally due to the formation or enlargement of a fault or crack of considerable length along a seismic zone in the earth's crust, it is quite natural that some of the weakest secondary points at the strained region should first give way and produce the minor shocks, before the dislocation or fracture along the whole extension of the focus produces the final great disturbance. In many instances, the fore-shocks were quite numerous, some of them attaining the intensity

of a semi-destructive motion. I mention next the more typical cases of the destructive earthquakes in Japan, which were preceded by these small shocks.

2. *Earthquake of Kagi (Formosa) of 1906.* The destructive earthquake in the Kagi prefecture, Formosa, on March 17, 1906, caused by the formation of the Baishiko and Chinsekiryo Faults, (the *Bulletin*, Vol. I, No. 2), was preceded about 5 minutes before by two strong shocks accompanied by very loud *jinari*, or sounds, like that due to a continuous discharge of gun. As these disturbances were quite unlike ordinary earthquakes felt there, the people were alarmed and took precaution for an escape in case of emergency, many running out of doors. Thus it happened that a comparatively small proportion of the inhabitants remained within doors at the time of the final great shock, a circumstance which must have considerably reduced the amount of casualties.

The occurrence of the premonitary shocks and *jinari* was also very striking in the cases of the Ansei and Riku-U earthquakes (§ § 3 and 4).

3. *Ansei earthquake in Central Japan.* The great earthquake of the 1st year of Ansei (1854), which was violently felt in the provinces of Iga, Ise, Omi, Yamato, Yamashiro, and Settsu, took place on July 9, at about 2 am.* The epifocus was a zone about 100 km. in length, which stretched from the vicinity of Yokkaichi (in Ise) to that of Nara (in Yamato), passing by the north of the town of Uyeno (in Iga), where considerable convul-

* This is different from the two great earthquakes of Dec. 23 and 24 in the same year, which originated off the Pacific coast of Japan. See also my note "On the earthquake zones in central Japan," the *Bulletin*, Vol. I, No. 3.

sions of the ground were produced. At the last named place, a moderate shock intense enough to drive people out of doors had been felt already two days before, namely, on the 7th, at 1 pm., succeeded by a stronger and unusually severe one at a little before 2 pm. These two shocks, which caused some cracks of the plastered walls, were followed by incessant *jinari*, or earth sounds, like thunders heard toward the north-west, the number of the minor shakings which occurred before the evening being 27. It is recorded that a traveller happening to arrive at Uyeno the same day was frightened by the *jinari*, so he went on and stayed at Kasagi, thereby escaping the risk of the disastrous earthquake. During the night of the 7th, the people were panic-stricken, no one going to bed. On the next day (the 8th), the weather was fine, and although the *jinari* did not cease, there was no specially severe shock, and the people began to be somewhat reassured. In the same evening, however, there were a few small shakings at about 8 pm., the final great earthquake having taken place the next morning at 2 am. The two shocks at 1 and 2 pm. on the 7th were also felt in Osaka.

4. ***Riku-U earthquake of Aug. 31, 1896, at 5h 6m pm.*** The Riku-U earthquake was most violent in the two counties of Senpoku and Hiraga, in the province of Ugo, and in the county of Nishi-Waga in the province of Rikuchu, producing the lines of dislocations known as the Senya and Kawafune Faults. In the epicentral district, there had occurred a shock of moderate intensity already 6 days before, namely, on Aug. 23rd, at 4 pm., followed daily by one or more small shakings. On the 31st, at 9 am., there was a strong shock, causing some damage to the dwelling

houses and throwing off the plastered walls of some old *dozo* (Japanese ware houses). Thereafter occurred nearly 30 shocks and *jinari*; amongst others the shock at 4h 42m pm. being the strongest. 24 minutes later on, at 5h 6m pm., the final great earthquake took place.

The epicentral district had, before August, 1896, been only rarely disturbed by earthquakes, and these latter had not been accompanied by *jinari*. But since the 23rd of August, the earthquakes were invariably accompanied by *jinari*, indicating their nature as fore-shocks and the proximity of their origins.

5. ***Tonan earthquake of Nov. 5, 1900, at 4h 41m pm.**** This earthquake originated off the coast of Izu, and was strongly felt in Kozu-shima, Mikura-jima, and Miyake-jima. At the last-named island, the first fore-shock, which was moderate in intensity, occurred at 8 am., on the 4th, followed by many moderate and slight shakings. At Mikura-jima, there was a moderate shock at 6 am., on the 5th, followed every five or ten minutes by others, the two strongest among which took place at 2 and 3 pm. respectively. In Kozu-shima, there was at 8h 10m am., on the 5th, a slight shock, followed by about a dozen moderate and slight ones, the final and largest earthquake having occurred at 4h 41m pm. the same day. According to the instrumental observations in Tokyo, there were 7 shocks, which preceded the final earthquake, and the first of which occurred at 9h 16m am., on the 5th, the strongest among these being that at 2h 10m pm.

6. ***Mino-Owari earthquake.*** The great Mino-Owari earthquake of Oct. 28, 1891, at 6h 37m am., was preceded by a strong shock, which took place 58 hours earlier, namely, at

* "Tonan" islands are the islands off the coast of Izu belonging to the Fuji volcanic chain.

9h 14m pm., on the 25th of the same month. In the epicentral area, *jinari* were heard from time to time before the great earthquake.

7. *Hokkaido earthquake of March 22, 1894.* The earthquake of March 22, 1894, which caused damage in the two provinces of Nemuro and Kushiro, along the north-eastern coast of Hokkaido, occurred at 7h 20m pm., the origin being sub-oceanic and at about 140 km. to the south-east of the city of Nemuro. This earthquake was preceded by the four shocks, whose times of occurrence and the intensity of motion at Nemuro were as follows:—

(i)	3^h	49^m	14^s	am.	Slight.
(ii)	2	22	55	pm.	Moderate.
(iii)	2	33	25	pm.	Slight.
(iv)	2	37	10	pm.	„

Thus the first fore-shock and the 2nd, which was the strongest among the four, had occurred respectively 15h 30m and 4h 57m before the final great earthquake.

The above mentioned four fore-shocks were observed with the ordinary Gray-Milne-Ewing type seismographs. Had the observation been made with the modern sensitive tromometer adapted to a continuous recorder, probably there would have been registered many other small insensible shakings.

8. *Remarks on the fore-shocks of the different earthquakes.* The time distributions of the Riku-U and Tonan fore-shocks, which occurred on the same days as the principal earthquakes themselves, present some mutual resemblance, as will be seen from the following table.

TABLE I.—FORE-SHOCKS OF THE RIKU-U AND TONAN EARTHQUAKES.

Riku-U Earthquake.			Tonan Earthquake.		
Time of Occurrence.	Successive Interval.		Time of Occurrence.	Successive Interval.	
$9^h 58^m$ am.			$9^h 16^m$ am.		
	$0^h 15^m$			$4^h 55^m$	
10 13 am.			2 11 pm.		
	4 54	**5^h 20^m**		0 37	**5^h 38^m**
3 07 pm.			2 48 pm.		
	0 11			0 06	
3 18 pm.			2 54 pm.		
		1 24		0 13	
4 42 pm.			3 07 pm.		**1 21**
				1 8	
			4 15 pm.		
		0 24			**0 27**
5 06 pm. (Great Eqke.)			4 42 pm.		

Thus the successive intervals between the times of occurrence of the fore-shocks were on the whole identical for the Riku-U and the Tonan earthquakes; the last strong fore-shocks having also occurred in the two cases by a nearly equal time interval, namely, 24 and 27 minutes respectively before the final disturbances.

The interval between the times of occurrence of the first strong fore-shock and the final great earthquake was, for the different cases, as follows :—

Ansei Eqke.	1^{day}	13^{hours}
Riku-U „	6	1
Tonan „	1	9
Mino-Owari Eqke.	2	10
Hokkaido „	0	$15\frac{1}{2}$

Again, the interval between the time of occurrence of the principal disturbance and the commencement of the last epoch of increased activity or frequency of the fore-shocks, was as follows :—

Ansei	Eqke.	....	6^h 0^m
Riku-U	„	....	8 34
Tonan	„	....	7 26
Hokkaido	„	....	4 57

The occurrence of fore-shocks is of course not limited to the few cases of the great earthquakes considered in § § 2 to 7. The same phenomena are shown by the large as well as the semi-destructive or strong earthquakes originating off the north-eastern coasts of Japan, along the Fuji volcanic chain, or off the eastern coast of Formosa. A few illustrative cases are given next.

9. ***Hokkaido earthquake of June 4, 1893.*** The earthquake of June 4, 1893, at 2h 27m am., shook the southern islands of the Kuriles. Thus, in Shikitan island, the shock was felt strongly, being followed by the *tsunami* along the coast, which reached a height of about 8 feet over the ordinary sea level. Again, in the Shibetori county (northern part of the Etrup island), the *tsunami* came on about 20 minutes after the shock, and caused an increase of water of 5 feet, forcing the river waters to flow upwards. The *tsunami* continued till 9 am., and the large waves were repeated five times, rocks having been thrown down at many places along the coast. Prior to this earthquake, there had occurred between the 1st and 3rd (June), five moderate and slight earthquakes, which shook the Kuriles or the eastern part of Hokkaido; there being one or more shocks each day between the 4th and the 13th, except the 10th and the 12th.

10. ***Karenko (Formosa) earthquake of 1905.**** The earthquake of Aug. 28, 1905, at 1h 24m pm., which was a local earthquake and which was semi-destructive at Karenko (Formosa), was preceded by several fore-shocks. Thus, at the latter town, there was a shock on the fore-noon of Aug. 8, several on the 13th, one each on the 18th, 19th, 20th, and 21st. A moderately strong shock occurred on the 26th, at 4h 50m pm., followed by a few slight ones, the final strong earthquake having taken place on the 28th. The after-shocks were also numerous, there being 20 or 30 of these on the same day and on the 29th.

11. ***Oshima (Izu) earthquakes of June 6 and 7, 1905.*** These two earthquakes, which caused some damage in the island of Oshima (Izu), were preceded by numerous small shocks. According to the report of the Governor of the island, there were more than 30 shakings between 1 am. and 10h 15m am., on the 5th, and a strong earthquake took place at 0h 35m am., on the 6th, causing several landslips in the island. The subsequent shocks were very frequent, more than 100 having happened before 11 am. the same day. On the 7th, at 2h 39m pm., there took place the principal earthquake, which were followed by more than 50 after-shocks in the course of the next 12 hours.

According to the tromometer observation in Tokyo, the first shock occurred on the 5th, at 10h 23m 26s am., between which time and the midnight of the 7th there were 28 others. Of these the 22nd one, which gave the greatest diagram, took place on the 7th at 2h 39m 30s pm. The following table gives a list of the earthquakes observed on the 5th to 7th in Tokyo.

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* See my note on the Bokusekikaku and Basshisho earthquake of Jan. 11, 1908, given elsewhere in this Number.

TABLE II.—OSHIMA (IZU) EARTHQUAKES OBSERVED IN TOKYO.

No.	Group.	Intensity in Tokyo. (*....Unfelt)	Time of Occurrence in Tokyo.	Mean Time of Occurrence in Tokyo.
1		*	5th $10^h 23^m 26^s$ am.	
2	A	*(*Strong* in Oshima)	6th 0 40 34 „	2 08 44 am.
3		*	0 43 37 „	
4		*	0 59 16 „	
5		*	1 13 43 „	
6		*(*Moderate* at Yokohama)	1 19 21 „	
7		*	1 38 56 „	
8		Slight (*Moderate* at Mera)	1 50 50 „	
9		*(*Moderate* at Yokohama)	2 05 09 „	
10		Slight (*Moderate* at Mera)	2 22 53 „	
11		*	2 50 45 „	
12		*	4 42 27 „	
13		*(*Moderate* at Yokohama)	5 17 13 „	
14	B	*	9 19 57 „	10 53 14 am.
15		*	9 23 08 „	
16		*	10 23 30 „	
17		*	0 30 14 pm.	
18		*	0 49 22 „	
19	C	*	5 28 22 „	7 28 39 pm.
20		*	9 28 55 „	
21	D	*	7th 6 12 05 am.	6 12 05 am.
22	E	Slight (*Strong* in Oshima, rather *strong* at Yokohama.)	2 29 30 pm.	2 39 30 pm.
23	After-shocks.	*	3 30 41 „	
24		*	3 44 18 „	
25		*	4 13 58 „	
26		*	8 43 54 „	
27		*	10 06 51 „	
28		*	11 09 18 „	

From the above table it will be seen that the 12 shocks, Nos. 2 to 13, occurred one closely after the other. Similarly the 5 shocks, Nos. 14 to 18, occurred together, being, however, separated from the preceding ones by a long interval. Thus the 21 shocks, Nos. 2 to 22, the last of which was the principal earthquake, may be divided more or less definitely into the five groups, A, B, C, D, and E, whose mean times of occurrence are found to be as follows :—

						Time Interval.
A (12 shocks)	6th:	2^h	8^m	44^s	am.	
						8^h 45^m
B (5 „)		10	53	14	„	
						8 35
C (2 „)		7	28	39	pm.	
						10 43
D (1 „)	7th:	6	12	05	am.	
						8 27
E (1 „)		2	39	30	pm.	

The successive intervals between the mean times of occurrence, which may be regarded as indicating the most active epoch of the different groups, were approximately equal to one another, varying from 8h 27m to 10h 43m. Further, the numbers of the shocks in the first four groups were respectively 12, 5, 2, and 1. That is to say, the fore-shocks of the earthquake, No. 22, occurred periodically in groups at a mean interval of about 8½ to 10½ hours, the activity or frequency being successively lessened, till the principal disturbance finally took place. This time relation of the fore-shocks is somewhat similar to that in the case of the Ansei earthquake of July 9, 1854.

The shocks, Nos. 23 to 28, were the after-shocks. It seems that on the occasion under consideration the fore-shocks were more numerous than the after-shocks.

12. ***Hachijo-jima earthquakes of May 13, 1908.*** The two principal earthquakes on May 13, 1908, at 5h 23m and 5h

37m am., originated under the ocean nearly midway between the Cape Omae-zaki of Totomi and the island of Hachijo-jima, at a distance of about 100 km. to the north-west of the latter.* There were 5 fore-shocks, which were registered at the meteorological observatory of Hachijo-jima on the Omori horizontal pendulum tromometer of 150 times in the EW direction, the results of the observation being shown in Table III. (See the diagram reproduced in Pl. XXIII.)

TABLE III.—EARTHQUAKE OBSERVATION AT HACHIJO-JIMA.

(Nos. 1–5 are fore-shocks).

No.	Time of occurrence at Hachijo-jima. (May 13)	Intensity.	Duration of Total Eqke.	Duration of Preliminary Tremor.	Max. 2a.	Difference between the successive times of occurrence.
1	$4^h 44^m 13^s$ am.	Insensible.	$1^m 15^s$	16.0^{sec}	0.043^{mm}	
						22^m 37^s
2	5 06 50	”	2 25	16.3	0.16	
						8 43
3	5 15 33	”	0 35	—	0.017	
						3 57
4	5 19 30	”	0 30	—	0.024	
						2 13
5	5 21 43	”	0 30	16.8	0.027	
						1 26
6	5 23 09	Strong.	Longer than 10^m	15.2	Large.	
7	5 37 55	”	Do.	—	Do.	

The time difference between the 1st and 2nd shocks was 22m 37s, while that between the 2nd and 3rd shocks was shorter and 8m 43s. The succeeding three intervals again decreased and were respectively 3m 57s, 2m 13s, and 1m 26s. Thus in the present case, the fore-shocks, the first of which had occurred 39m before the principal earthquake, quickly increased in fre-

* These two earthquakes are discussed more in detail elsewhere in this Number.

quency till the latter was finally produced, indicating a rapid progress of disturbance at the focus.

13. ***Distinction between local and large earthquakes.*** A local shock, which may be regarded as originating from a centre or point and is sometimes destructive at the epicentre, is characterized by the smallness of its total energy. Such a disturbance seems generally to be unaccompanied by the fore-shocks. On the other hand, large earthquakes, whose focus has a considerable extension and may be regarded as being equivalent to a collection of a great number of local centres of disturbance arranged along a zone, seem to be preceded on many occasions by minor shocks. The fore-shocks of a great earthquake may first occur several days or several hours before the latter, and their time distribution may be sometimes more or less periodical.

The phenomena of fore-shocks furnish a very interesting subject of study, and give a practical importance to the tromometrical observation in earthquake countries. My belief is that a large destructive earthquake will be foretold in its epicentral region by some fore-shocks.

Tokyo. May, 1908.

Notes on the Secondary Causes of Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XXIV–XXVIII.

CONTENTS.

1. *Introduction.* Earthquakes are caused by some sudden underground disturbances, which may consist in the formation or extension of a fault, the production of a fissure or cavity, the subsidence or upheaval of a piece of ground, etc. These disturbances themselves are, however, the results of the stresses going on in the earth's crust for a considerable interval of time; a great shock at a given portion of a seismic region occurring in general only once in several years or even several centuries. When, therefore, an earthquake is about to happen, the earth's crust in the vicinity of its focus is in a critical condition and must be

very sensitive to the effects of changes in the atmospheric pressure, the amount of precipitation of rain and snow, the variation in the weight of the sea water in the tidal movement, etc. These external agencies, which constitute the *secondary earthquake causes* have evidently an important bearing on the seismic phenomena, and the present paper contains some notes on the relations of these to the time distribution of the shocks in Japan.*

2. *Examples of local characteristics.* The following are some examples of the cases, in which strong or great earthquakes in a given region occurred in approximately the same parts of the year or of the day.

(*a*) The destructive earthquake of Kumamoto (Kyushu) took place on July 28, 1889. Its numerous after-shocks gradually decreased in frequency till 1894, when a strong earthquake occurred on Aug. 8. A third strong shock took place on Aug. 27, 1905, followed by a fourth on March 10, 1907. The times of occurrence of these 4 earthquakes, the three last of which were not destructive, are given in the following table.

TABLE I.—LIST OF THE SEVERE KUMAMOTO EARTHQUAKES.

No.	Date.	Time of Occurrence.
1	July 28, 1889.	$11^h\ 40^m$ pm.
2	Aug. 8, 1894.	11 19 "
3	Aug. 27, 1902.	10 42 "
4	March 10, 1907.	10 03 "

(*b*) The severe earthquake of May 26, 1898, at $3^h\ 0^m\ 0^s$ am.,

* The times are always given in the 1st Normal Japan Time, or that of longitude 135° E., of Greenwich.

which caused some slight damage, originated in the District of Uonuma, near the town of Muikamachi, in the province of Echigo. Six years later, namely, in 1904, a second severe earthquake took place on May 8, at 4h 23m 49s am., the origin being close to that of the preceding shock.

(*c*) The great sea-waves of 1896 along the north-eastern coast of the Main Island, known as the Sanriku* *tsunami*, were caused by an earthquake, which took place on June 15, at 7½ pm. Five years later, namely, in 1901, there was also some tidal disturbances accompanying an earthquake which occurred on June 15, at 6½ pm.

(*d*) The great Shonai earthquake of 1894, which caused enormous damage to life and property in the city of Sakata and the vicinity (provinces of Uzen and Ugo), took place on Oct. 22, at 5h 35m pm. The great Riku-U earthquake of 1896 took place on Aug. 31, at 5h 6m pm.

Thus it will be seen that the first three Kumamoto earthquakes, (*a*), were in July or August, while all the four occurred late in the evening, namely, between 10h 03m pm. and 11h 40m pm. The two Echigo earthquakes, (*b*), took place in the month of May, at 3h 0m to 4h 23m am. The two Sanriku earthquakes, (*c*), occurred on June 15, at 6½ to 7½ pm. Finally, the two great destructive earthquakes of Northern Japan, (*d*), occurred at 5h 6m to 5h 35m pm.

From these examples it may be inferred that great and strong earthquakes in a given district often have a tendency to occur in certain months of the year, or at certain hours of the day. This is to be regarded as indicating the local peculiarities, probably

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* *Sanriku* denotes the three large provinces of Rikuzen, Rikuchu, and Mutsu, which form the north-eastern part of the Main Island.

depending on the tidal movement of the sea water and the annual and diurnal variations of the barometric pressure. As an example relating to great earthquakes occurring along an extensive seismic zone, I mention the four recent destructive shocks of San Francisco, Mexico, and Central America, whose dates were as follows :—

TABLE II.—EARTHQUAKES ALONG THE SOUTH-WESTERN COAST OF NORTH AMERICA.

Date.	Earthquake.
April 19, 1902.	Guatemala.
„ 18, 1906.	Earthquake of San Francisco.
„ 15, 1907.	Mexico.
March 26, 1908.	„

Thus the first three shocks occurred all in the month of April, between 15th and 19th, while the 4th occurred in the latter part of March.

3. ***Strong earthquakes in Shimosa and Hitachi.*** The following table is a list of the earthquakes felt strongly at Mizukaido, Sahara and other places along the lower course of the Tone-*gawa*, which forms the boundary between the two provinces of Shimosa and Hitachi. The land areas of disturbance, within which the motion was sensible or was recorded by the ordinary Gray-Milne-Ewing type seismographs, were in each case over 1,000 sq. *ri*.

TABLE III.—STRONG EARTHQUAKES IN SHIMOSA AND HITACHI.

No.	Date.	Time of Earthquake Occurrence.
1	March 3, 1902.	9^h 13^m am.
2	„ 25, „	2 35 pm.
3	Aug. 8, „	8 37 am.
4	Dec. 14, „	1 57 pm.
5	„ 31, „	2 38 pm.
6	May 8, 1904.	7 24 am.
7	June 30, „	8 21 am.

It will be observed that four of the seven earthquakes given in the above table, namely, Nos. 1, 3, 6, and 7, occurred at 7 to 9 am., while the remaining three, Nos. 2, 4, and 5, occurred at 1 to 2 pm. These two groups of the times of occurrence may be regarded as approximately agreeing with a pair of epochs of the maximum and minimum in the diurnal variation of the barometric pressure.

4. ***General relations of the secondary causes on earthquake frequency.*** The secondary causes of earthquakes as enumerated in § 1 make themselves sensible by the variation of the vertical pressure exerted on the earth's crust. Let us examine a few simple cases of the relations of the secondary causes to earthquake frequency.

(*a*) Suppose *ab* to be a horizontal layer of the earth's crust, which is undergoing a tension parallel to its plane. Then an increase or decrease in the pressure, *c*, applied vertically to it, will equally accelerate the formation of a vertical rupture or crack. (Figs. 1 and 2.) In the case the layer *ab* is undergoing

a compression in its plane, a variation in the external pressure may tend to produce a dislocation or slipping.

(*b*) When the layer *ab* is being pushed upwards from below, a decrease in the barometric pressure, the weight of the sea waters, etc., will favour the occurrence of the rupture.

(*c*) When the layer *ab* is being pushed down, the increase in the pressure due to the secondary causes will tend to the same result.

Fig. 1.

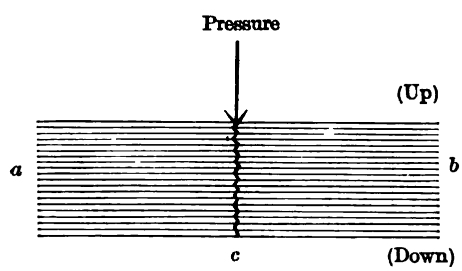
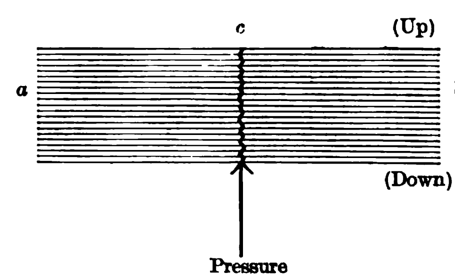


Fig. 2.



I give next a few cases illustrating some of these principles.

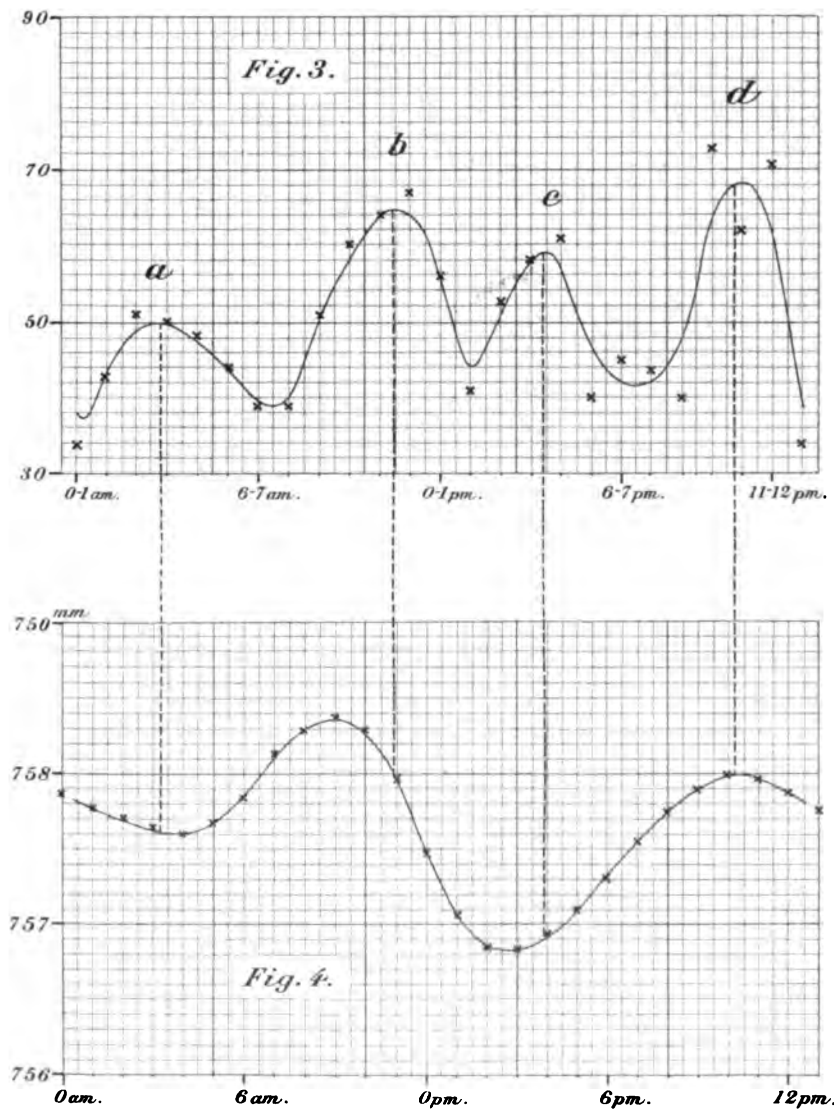
5. *Jinari* at Arima, 1899-1900.* The earth sounds, or *jinari*, at the famous hot spring place of Arima, near Kobe (province of Settsu), began on July 5, 1899, and were very numerous during the several succeding weeks. The maximum daily number, probably about 200, was reached at the beginning of August, thence the frequency gradually decreasing. After the 8th of August, the times of occurrence of these *jinari* were carefully recorded at the city office of Arima; the total number during the rest of the month being 584. In the four months of September to December

* The Japanese word "jinari," which signifies *earth sound*, may be used to denote earthquake sounds as well as those sounds heard in volcanic and other districts which are accompanied only by very slight tremblings of the ground.

Diurnal Variations.

Fig. 3. ...... Frequency of the *Jinari* at Arima.

Fig. 4. ...... Barometric Pressure at Kobe.



there were altogether 650 of the *jinari*, which did not completely cease in the course of the next year.

The origin of disturbance was situated at a distance of about 2 km to the south of Arima among the Rokko Mountain, whose formation is of granite and diorite. Judging from the frequency distribution of the *jinari* in the vicinity, the focal depth was very small, and probably between ½ and 2 km. The sounds, which were sometimes very loud, were mostly like that caused by the discharge of gun at a distance, or falling of a heavy mass on the ground. The tremblings of the ground, which followed the sounds after an interval of 0.5 to 1.0 second, were generally slight. On a few occasions, however, the earthquake mevement was quite sharp, and caused the falling down of some roof tiles, rolling down of rock fragments from mountain slopes, etc.

Table IV gives the hourly distribution of the 1,234 *jinari* recorded at Arima between Aug. 8 and Dec. 31, 1899, and the mean hourly barometric height during the same interval for the meteorological observatory of Kobe, which was not much distant from the origin of disturbance.

TABLE IV.—DIURNAL VARIATIONS OF THE FREQUENCY OF THE *JINARI* AT ARIMA AND THE BAROMETRIC PRESSURE AT KOBE.

Jinari at Arima.		Atmospheric Pressure at Kobe.	
Hour Interval.	Number of *jinari*.	Hour.	Barometric Height.*
0^h— 1^h AM.	34	1^h AM.	700 + 57.78^{mm}
1— 2	43	2	57.72
2— 3	51	3	57.66
3— 4	50	4	57.61
4— 5	48	5	57.68

Jinari at Arima.		Atmospheric Pressure at Kobe.	
Hour Interval.	Number of *jinari*.	Hour.	Barometric Height.*
5^h— 6^h AM.	44	6^h AM.	$57\overset{mm}{.}85$
6— 7	39	7	58.15
7— 8	39	8	58.29
8— 9	51	9	58.39
9—10	60	10	58.30
10—11	64	11	57.98
11—12	67	Noon	57.50
0— 1 PM.	56	1 PM.	57.07
1— 2	41	2	56.85
2— 3	53	3	56.84
3— 4	58	4	56.95
4— 5	61	5	57.11
5— 6	40	6	57.30
6— 7	45	7	57.56
7— 8	44	8	57.76
8— 9	40	9	57.91
9—10	73	10	58.02
10—11	62	11	57.98
11—12	71	Midnight.	57.88
Sum......	**1234**		
Mean	**51.4**		

* Reduction to standard gravity = −0.70 mm.
Reduction to mean sea level = +5.40 mm.

As illustrated in Fig. 3, the diurnal variation of the frequency of the *jinari* at Arima shows very clearly 4 maxima *a*, *b*, *c*, *d*, and the 4 corresponding minima, indicating a six-hour periodicity. Further, it will be observed from Fig. 4 that the diurnal variation of the barometric pressure at Kobe shows

the two maxima and two minima, indicating as usual a 12-hour periodicity. Comparing the two figures, we see that the mutual relation between the *jinari* frequency and the barometric pressure is striking, the two maxima, *b* and *d*, and the two other maxima, *a* and *c*, of the former occurring nearly at the same hours respectively with the two maxima and minima of the latter. The epochs of the 4 maxima *a*, *b*, *c*, *d*, indicated by the mean frequency curve of the *jinari* are as follows :—

1st	Maximum,	(*a*)...........	about 3 am.
2nd	„	(*b*)...........	„ 11 „
3rd	„	(*c*)...........	„ 4 pm.
4th	„	(*d*).....	between 10-11 „

The differences between the 4 maxima *a*, *c*, *b*, *d*, and the corresponding minima (the preceding minimum in each case, say), are as follows :—

	Difference in the frequency.
1st Max. and Min.	17
2nd „	28
3rd „	20
4th „	33
Average	**25**

This average difference may approximately be regarded as the effect due to the barometric pressure, and corresponds to about 50% of the mean hourly frequency, namely, 51.4.

As the *jinari* are purely local phenomena of a shallow origin, it is to be quite expected that their frequency should be influenced by the barometric pressure. What was said above indicates that both the increase and the decrease of the pressure equally causes an increase in the frequency of the *jinari*, in accordance with the principle stated in § 4, (a).

6. ***Diurnal variation of earthquake frequency in Tokyo.*** The diurnal variation of the seismic frequency in Tokyo also shows clearly the same characteristic as the *jinari* at Arima. The following table gives the distribution in the 24 hours of the day of 2,208 earthquakes instrumentally observed during the 24 years, 1876–1899, at the Central Meteorological Observatory, and the mean hourly values of the barometric pressure at the same place.*

TABLE V.—DIURNAL VARIATIONS OF THE FREQUENCY OF EARTHQUAKES AND THE BAROMETRIC PRESSURE, IN TOKYO.

Earthquakes (1876–1899).		Atmospheric Pressure.	
Hour Interval.	Frequency.	Hour.	Barometric Height.†
0^h— 1^h AM.	92	1^h AM.	700 + 59.33 mm
1— 2	81	2	59.24
2— 3	90	3	59.18
3— 4	85	4	59.21
4— 5	71	5	59.35
5— 6	87	6	59.58
6— 7	95	7	59.79
7— 8	92	8	59.95
8— 9	96	9	60.00
9—10	113	10	59.88
10—11	93	11	59.49
11—12	84	Noon	58.98
0— 1 PM.	79	1 PM.	58.56
1— 2	91	2	58.31
2— 3	85	3	58.27

* Reproduced from the *Publications of the Earthquake Investigation Committee*, No. 8.

† With the freezing point correction. Reduction to standard gravity = −0.63 mm; reduction to sea-level = +1.94 mm.

Fig. 5. Seismic Frequency.

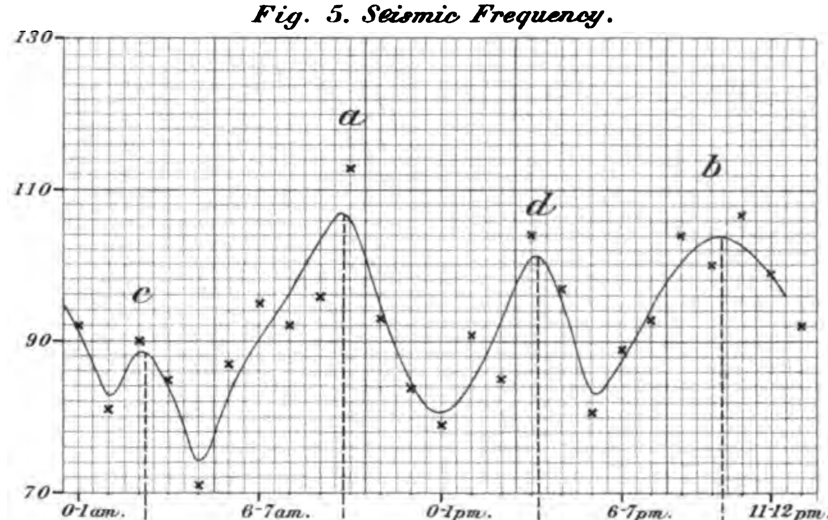
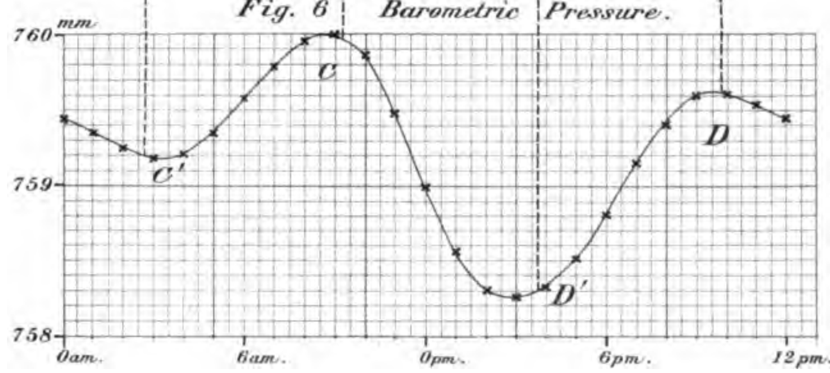


Fig. 6 Barometric Pressure.



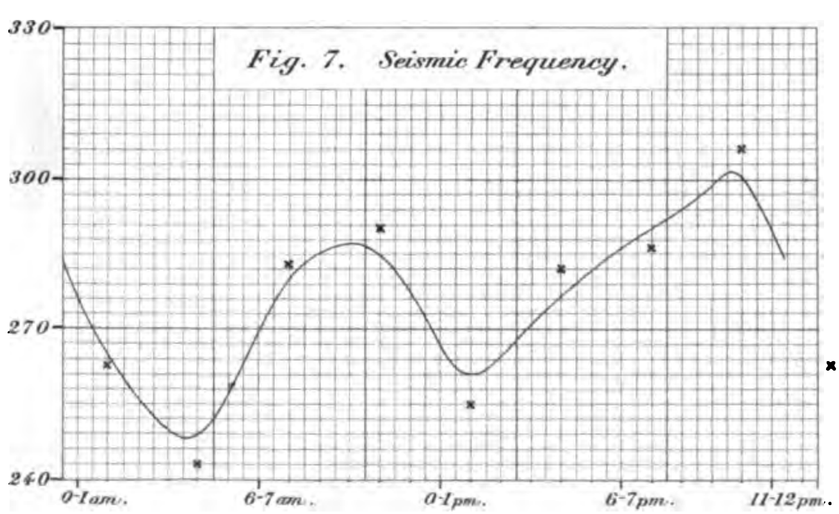


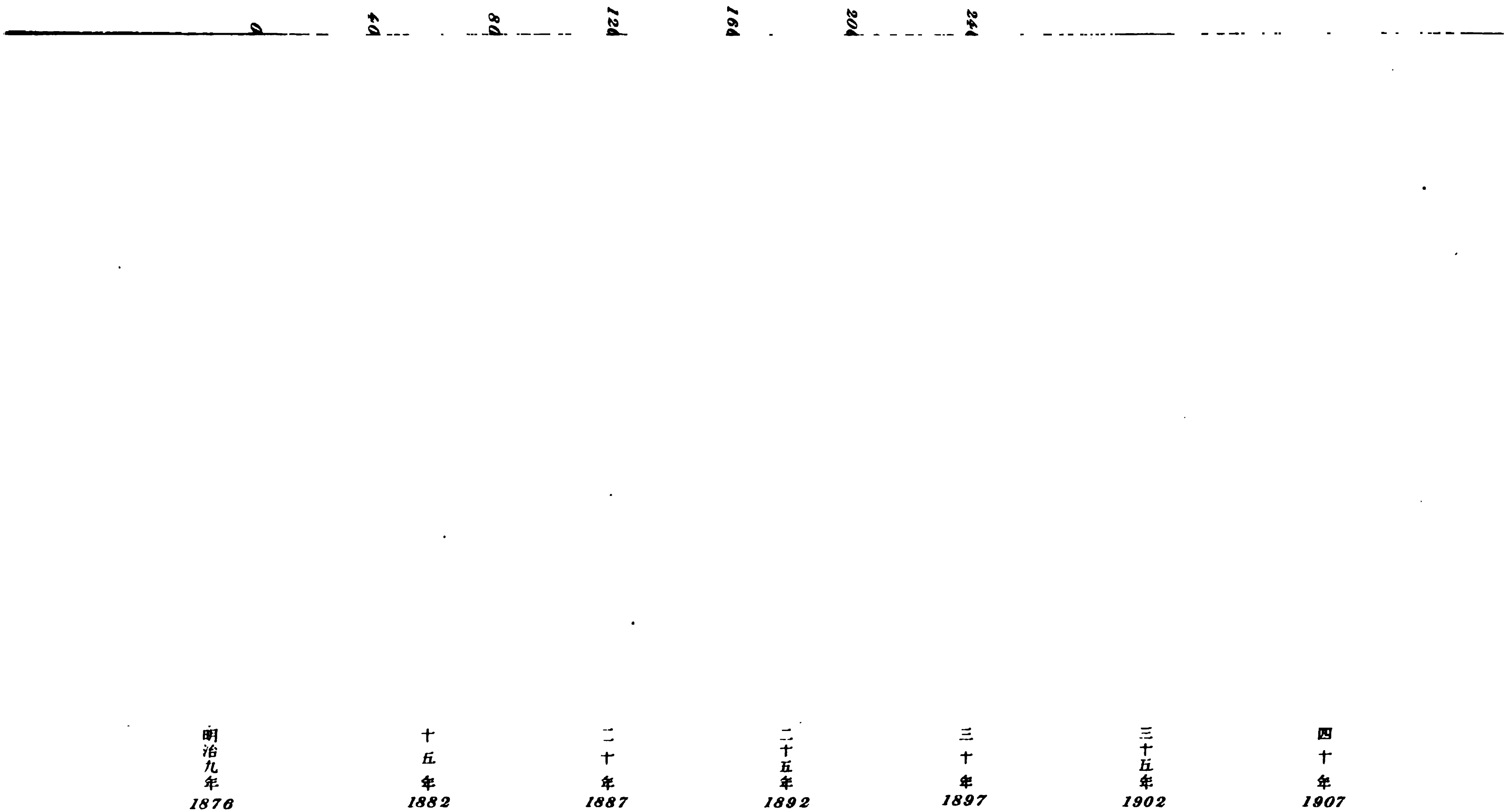
Fig. 7. Seismic Frequency.

TABLE V. (Cont.)

Earthquakes (1876-1899).		Atmospheric Pressure.	
Hour Interval.	Frequency.	Hour.	Barometric Height.
3^h— 4^h PM.	104	4 PM.	700 + 58.33 mm
4— 5	97	5	58.52
5— 6	81	6	58.82
6— 7	89	7	59.14
7— 8	93	8	59.40
8— 9	104	9	59.60
9—10	100	10	59.61
10—11	107	11	59.54
11—12	99	Midnight.	59.43

Fig. 7, drawn from the 3-hourly earthquake numbers, represents the mean course of the diurnal variation of the seismic frequency, which will be seen to be on the whole parallel to that of the atmospheric pressure. That is to say, the ordinary (non-destructive) earthquakes felt in Tokyo happen more frequently with the high barometer than with the low, illustrating a case stated in § 4, (*c*). The curve of the hourly seismic frequency (Fig. 5) indicates, however, 4 maxima, namely, a pair of principal maxima, *a* and *b*, respectively at 9–10 am. and 9–10 pm., and a pair of the secondary maxima, *c* and *d*, respectively at 2–3 am. and 3–4 pm. On comparing Figs. 5 and 6, it will be noted that, according to the principle of § 4, (*a*), the two maxima, *C* and *D*, and the two minima, *C′* and *D′*, of the barometric pressure correspond respectively to the pair of the principal maxima and the pair of the secondary maxima, of the seismic frequency.

7. Precipitation and yearly earthquake frequency in Tokyo. It is quite conceivable that the yearly earthquake frequency in Tokyo is related to the amount of the precipitation of rain and snow in the plain of Musashi, on which the city is situated, or along the north-western coast of the Main Island, where a large amount of the moisture is deposited during the winter months. I give in the second column of Table VI, the yearly numbers of the earthquakes which were not teleseismic and which were instrumentally recorded during the 32 years, 1876–1907, at the Central Meteorological Observatory. The observations were made at first with Palmieri's seismograph, but since 1887 by means of a Gray-Milne-Ewing type seismograph. It will be observed that the earthquake number was minimum (=32) in 1883, and maximum (=216) in 1896, thence the frequency is on the whole decreasing. For the sake of reference, I give in Table VII, the mean barometric pressure and temperature, and the amount of precipitation in Tokyo during each of these 32 years. As a trial I have taken into consideration the amount of precipitation at Niigata and Akita, both situated along the Japan Sea coast, as the observations at these two places date since 1882 and 1883, respectively over the long intervals of 26 and 25 years (Table VI). The city of Niigata, about 260 km to the NNW of Tokyo, is situated at the mouth of the Shinano-*gawa*, the quarternary plain about the lower course of the latter and the neighbouring rivers being the largest in Japan next to the Tokyo plain. The city of Akita is at about 440 km to the north of Tokyo.


0
40
80
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200
240
明治九年
1876
十五年
1882
二十年
1887
二十五年
1892
三十年
1897
三十五年
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Pl. XXVII.

Fig. 9. Variation of the Yearly Amount of the Precipitation at Niigata.
1882–1907.

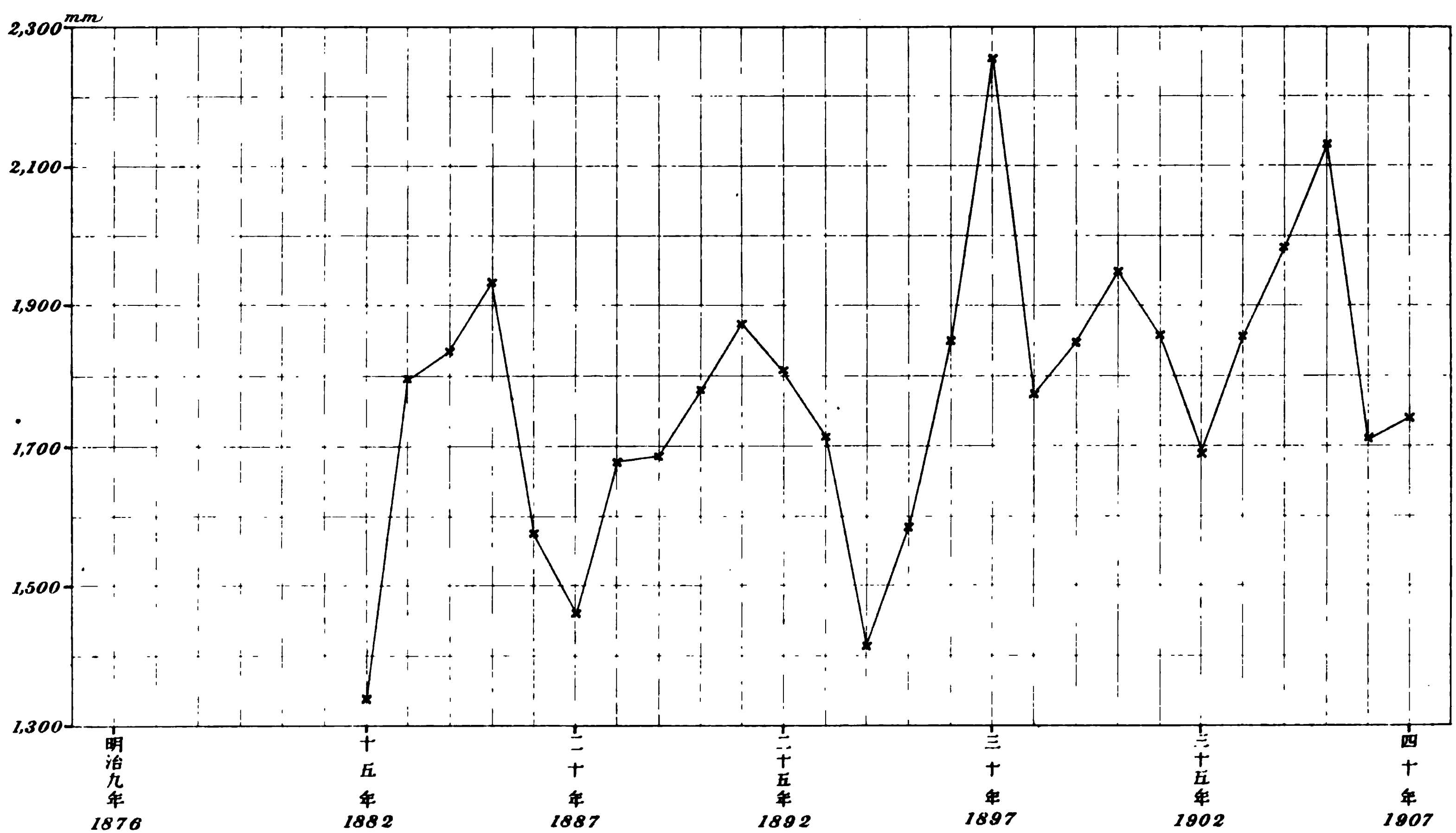

Fig. 10. Variation of the Yearly Amount of the Precipitation at Akita.
1883-1907.

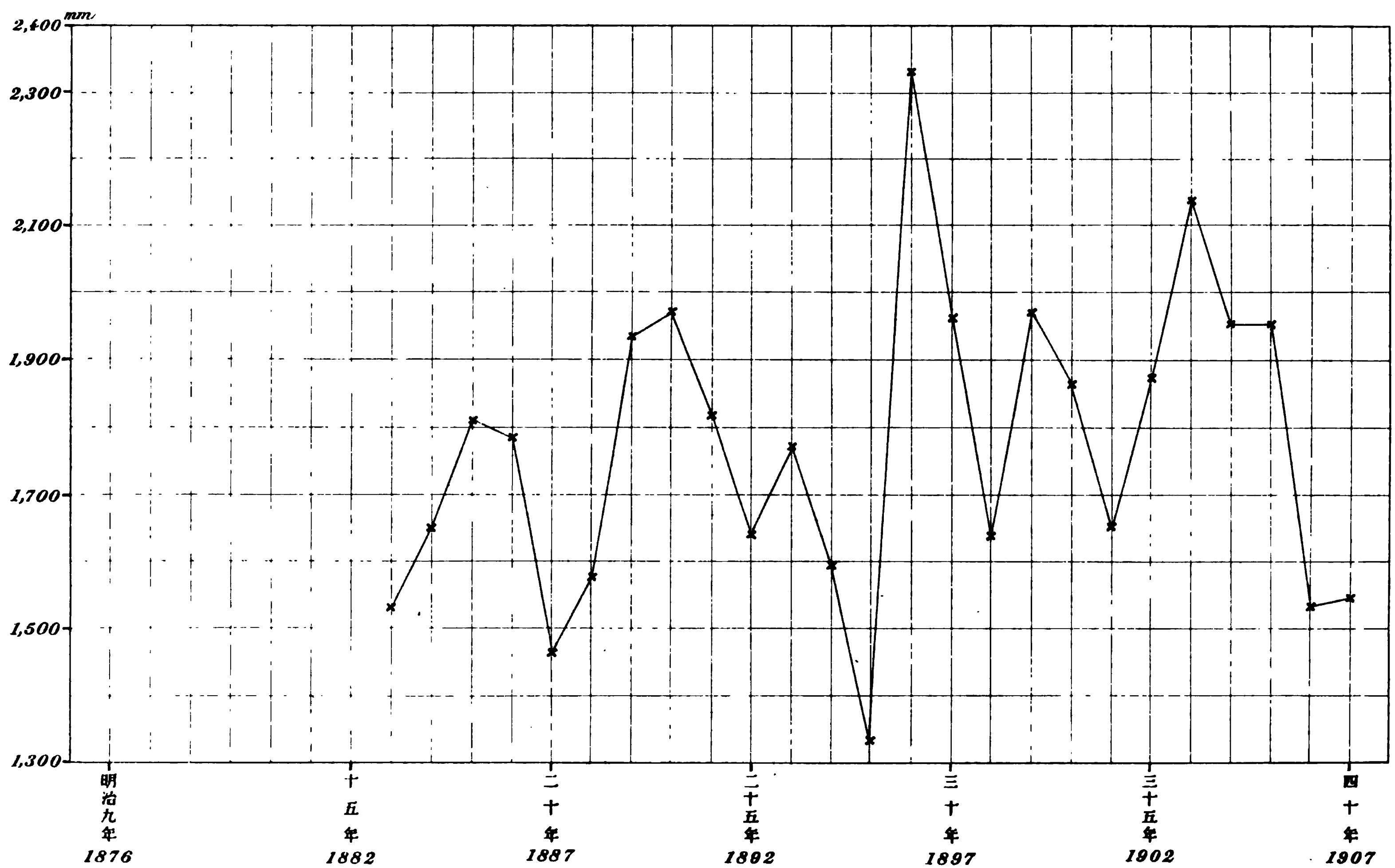

TABLE VI.—YEARLY NUMBERS OF EARTHQUAKES IN TOKYO, (1876–1907) AND THE AMOUNT OF PRECIPITATION AT NIIGATA AND AKITA (1882–1907.)

Year.	Number of Earthquakes in Tokyo.	Amount of Precipitation.		
		Niigata.	Akita.	*Mean.*
1876	56			
1877	71			
1878	50			
1879	70			
1880	77			
1881	64			
1882	46	1341.3mm	— mm	— mm
1883	32	1796.5	1536.4	1666.5
1884	68	1839.3	1650.1	1744.7
1885	68	1935.9	1809.5	1872.7
1886	54	1580.1	1786.0	1683.1
1887	80	1467.9	1465.3	1466.6
1888	101	1681.3	1579.6	1630.5
1889	113	1889.3	1937.6	1913.5
1890	93	1784.0	1971.6	1877.8
1891	123	1877.7	1820.0	1848.9
1892	73	1809.9	1641.4	1725.7
1893	59	1717.9	1775.2	1746.6
1894	101	1418.0	1596.1	1507.1
1895	122	1586.7	1331.0	1458.9
1896	216	1854.1	2335.1	2094.6
1897	164	2257.8	1964.5	2111.2
1898	144	1777.6	1639.0	1708.3
1899	124	1853.0	1972.3	1912.7
1900	156	1953.3	1864.0	1908.7
1901	121	1861.4	1651.6	1756.5
1902	116	1693.3	1853.8	1773.6
1903	104	1858.9	2141.4	2000.2
1904	155	1986.5	1956.2	1971.4
1905	154	2133.5	1957.2	2045.4
1906	132	1713.2	1535.0	1624.1
1907	100	1741.7	1548.8	1645.3

TABLE VII.—MEAN BAROMETRIC PRESSURE AND TEMPERATURE, AND THE AMOUNT OF PRECIPITATION.

TOKYO. 1876—1907.

Year	Mean Barometric Pressure.*	Mean Temperature.	Annual Amount of Precipitation.
	mm	°	mm
1876	761.1	13.6 C	1756.4
1877	61.5	13.9	1317.3
1878	61.5	13.6	1764.2
1879	61.0	14.4	1492.7
1880	61.3	13.9	1685.7
1881	61.4	13.6	1444.4
1882	61.5	13.8	1478.3
1883	61.4	13.2	1552.6
1884	61.2	12.8	1314.8
1885	61.3	13.0	1531.7
1886	61.5	13.9	1286.3
1887	60.8	13.8	1250.0
1888	61.0	13.5	1378.5
1889	61.2	13.3	1319.3
1890	61.0	15.0	1958.2
1891	61.2	14.4	1220.8
1892	61.0	14.0	1715.1
1893	61.2	13.8	1161.3
1894	61.5	14.8	1320.8
1895	61.1	13.8	1397.8
1896	61.5	14.0	1373.9
1897	61.6	13.2	1497.2
1898	61.2	13.9	1711.9
1899	60.7	13.8	1649.1
1900	61.0	13.6	1188.0
1901	60.3	13.8	1588.9
1902	60.7	13.7	1753.7
1903	61.1	13.7	1912.2
1904	60.8	13.7	1381.8
1905	61.2	13.5	1330.1
1906	60.3	13.1	1519.5
1907	60.7	13.5	1640.4

* With the freezing point, sea level, and gravity corrections.

The variation from year to year of the earthquake number in Tokyo seems to have no marked general relation to that of the amount of the precipitation, or to the mean temperature and barometric pressure, at the same place. The Tokyo seismic frequency varied, however, in a close parallelism with the amount of the precipitation at Niigata and Akita. As will be seen from Figs. 9 and 10, both the absolute amount of the precipitation and the general course of its variation with years were nearly alike for these two places; the annual amount of precipitation being in each case taken to be a function of the time. Fig. 8 illustrates the variation of the yearly seismic frequency in Tokyo, and of the mean amount of the precipitation at Niigata and Akita (Table VI). The curve for the seismic frequency will be observed to be, on the whole, similar to that for the precipitation (drawn in red); the highest values in both occurring in the two years 1896 and 1897. In fact the different maxima in the frequency correspond to those in the amount of the precipitation, and the two curves run nearly parallel to each other. This coincidence is probably not accidental, and the variation of the yearly number of the earthquakes felt in Tokyo may be taken to be approximately proportional to the amount of precipitation along the north-western side of the Main Island.

8. ***Weather and destructive earthquakes.*** In Japan, India, America, and probably also in some other countries, earthquakes are popularly supposed to occur specially in the so-called *earthquake weather*, namely, on sultry days. This is, however, not true, at least not generally. On the other hand, Carlyle says in his *French Revolution* : "Hope ushers in a Revolution,—as earthquakes are preceded by bright weather." Whatever may be the authority in seismological matters of the great British author, there were certainly many earthquakes which occurred in bright weather.

Indeed the relation of earthquakes to weather is a very complicated question, as it involves the considerations of the atmospheric pressure, temperature and moisture, and the precipitation. Large shocks and small shakings are often governed, in their time distribution, by entirely opposite laws. So are also earthquakes of inland origin and those of submarine origin. For the present, I shall confine myself to the consideration of some of the great destructive earthquakes in Japan, of which we have the record of the state of the accompanying weather. There were 18 of these shocks, as follows.

TABLE VIII.—RELATION TO WEATHER OF THE DESTRUCTIVE EARTHQUAKES.

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
1	正平十六年六月廿四日 Aug. 3, 1361.	4 am.	Kinai Provinces,* Kii, Awa. (Accompanied by *tsunami*.**)	Fair (Kyoto)
2	明應七年八月廿五日 Sept. 20, 1498.	9 am.	Ise, Totomi, Mikawa, Kai, Suruga, Sagami, Izu. (Accompanied by *tsunami*.)	Do.
3	永正七年八月八日 Sept. 21, 1510.	3 am.	Settsu. The *torii*, or temple gate of Shitenno-ji, overthrown.	Do.
4	天正十三年十一月廿九日 Jan. 18, 1585.	Midnight.	Kinai Provinces, Omi, Mino, Owari, Ise, Mikawa. (Accompanied by *tsunami*.)	Snowy (Kyoto).
5	慶長元年閏七月十二日 Sept. 4, 1596.	1 am.	Yamashiro, Settsu, Izumi. (The great Keicho Earthquake, which destroyed the castle of Fushimi.)	Fair (Kyoto). Continued to be fair till 8th; rain and wind on 9th.
6	寛文二年五月一日 June 16, 1662.	11 am.	Kinai Provinces, Tanba, Wakasa, Omi, Mino, Ise, Suruga, Mikawa, Shinano. (The Kwanbun Earthquake).	In Kyoto, occasional rains from the previous evening; heavy rainfall at the time of the shock.

* The Kinai Provinces are Yamashiro, Yamato, Kawachi, Izumi, and Settsu.

** *Tsunami* denotes the great tidal disturbances, which may be caused by submarine earthquakes, volcanic eruptions, or by barometric depressions.

TABLE VIII. *(Cont.)*

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
7	寛文五年十一月廿七日 Feb. 1, 1666.	5 pm.	Takata (Echigo.)	Heavy snow fall, to the amount of some 15 feet.
8	元祿十六年十一月廿三日 Dec. 31, 1703.	3 am.	Yedo (Tokyo), Sagami, Awa, Kazusa. Accompanied by *tsunami*. (The Genroku Earthquake.)	Fair in Yedo (Tokyo). Calm and clear in Kyoto.
9	寳永四年十月四日 Oct. 28, 1707.	1 pm.	Kyushu to Tokaido. (The Hoei Earthquake, the greatest of the disturbances that ever shook Japan in the historical times.)	In Kyoto, clear and calm. In Tosa (Shikoku), very clear and bright, with no cloud at all; no wind throughout the day, and warm as in summer.
10	享和二年十一月十六日 Dec. 9, 1802.	Early morning.	Ogi (province of Sado.)	On the 8th, very clear and calm.
11	文政十一年十一月十二日 Dec. 18, 1828.	7 am.	Sanjo and vicinity (province of Echigo). (The Bunsei Earthquake.)	Great snow storm in the night of the 17th, and some rain and strong winds in the morning of the 18th.
12	天保元年七月二日 Aug. 19, 1830.	4 pm.	Kyoto and the Kinai Provinces. (The Tenpo Earthquake.)	Fair on the 18th—20th; heavy rain on the 21st; fair on the 22nd and 23rd; some rain on the 24th.
13	弘化四年三月廿四日 May 8, 1847.	10 pm.	Shinano and Echigo. (The great Zenkoji Earthquake.)	Clear, calm and warm, in the day time and the evening of the 8th.
14	安政元年六月十五日 July 9, 1854.	2 am.	Kinai Provinces, Iga, Ise, Kii. (One of the Ansei Earthquakes.)	On the 8th, fair during the day time, with rain and thunder in the evening (Kyoto).
15	安政元年十一月四日 Dec. 23, 1854.	9 am.	Tokaido. (One of the Ansei Earthquakes.)	Fair in Kyoto, Kii, and the Tokaido provinces.
16	安政元年十一月五日 Dec. 24, 1854.	5 pm.	Saikaido and Nankaido. (One of the Ansei Earthquakes.)	Same fair weather as on the provious day.
17	安政二年十月二日 Nov. 11, 1855.	10 pm.	Yedo (Tokyo.)	During the day, cloudy and slightly rainy. Cleared up in the evening, the wind being unusually calm.

TABLE VIII. *(Cont.)*

No.	Date.	Time of Occurrence.	Provinces strongly shaken.	Remarks on the Weather.
18	明治廿四年十月廿八日 Oct. 28, 1891.	6.37 am.	Mino-Owari Eqke.	At Gifu, the amount of precipitation during October 1891 was unusually small, there being no rain fall at all between the 1st and 22nd of the month. Since the 23rd, there were some occasional rains, which ceased completely at about 6h 40m am. on the 28th. The sky began to clear up from about 8h 15m am. in the same morning. The great earthquake took place at 6h 37m am., while the barometer was falling.

The relation to weather of the 18 earthquakes mentioned in the above table was as follows :—

Fair or clear weather	....	12	earthquakes.
Cloudy ,,	....	2	,,
Rainy or snowy ,,	....	3	,,
Rainy and windy ,,	....	1	,,

Thus it will be observed that 12 *out of the* 18 *earthquakes occurred in fair or clear weathers.* There was only one case, No. 7, in which the weather was rainy and windy. This, however, took place in Echigo, where there is during the winter months much wind and precipitation, so that it is not at all surprising that a strong earthquake should occur at Takata in a bad weather. Again, of the 18 destructive earthquakes, none occurred in a wet sultry weather, which is a contradiction to the popular belief before referred to. It is extremely probable that *great shocks do not occur in very bad weathers.*

The two great earthquakes of Hoei and Zenkoji (Nos. 9 and

13) and the Ogi earthquake (No. 10), whose dates were from Oct. 28 to May 8, took place each on a very clear, calm and warm day. It is probable that these destructive seismic disturbances happened when, after the passage of the atmospheric depressions, the whole of Japan was covered by the high pressure, so that the weather was fine and calm, and consequently warm in the day time; just in the same way as a snow storm in Tokyo is generally followed by a bright and warm day.

9. ***Earthquake weather and fires.*** None of the destructive earthquakes in Japan ever happened in the midst of a violent storm. This is a very fortunate circumstance in connection with the disastrous fires which so often break out after great shocks. Thus, on the occasion of the Yedo (Tokyo) earthquake of the 2nd year of Ansei, (No. 17), which took place at 10 pm., and which caused a loss of about 7,000 lives, fires broke out at 32 different places in the city. Owing, however, to the stillness of air, all these fires were put out before the day-break, the aggregate area of the burnt districts being about 1 square mile. This amount of the damage is much smaller than in the cases of some of the metropolitan fires, which were not connected with earthquakes. For instance, the famous Maruyama fire of the 3rd year of Meireki, on March 2, 1657, caused the loss of 107,046 lives; while the great fire of April 1, 1772, began at Meguro and reached, within 24 hours, to the Koishikawa, Shitaya, and other northern districts, reducing to ashes all the buildings within an area 24 km in length and 4 km in width. These and other gigantic fires in Yedo (Tokyo) all occurred on the occasion of great stroms, and, in the case of the Meireki catastrophe, the wind velocity is supposed to have reached 60 miles per hour. As, however, the destructive earthquakes never occurred on

stormy days it is to be expected that the fires following these would not extend so enormously, provided means be properly taken for subduing the flames.*

10. ***Effects of barometric pressure and tides.*** Let us next consider the effects on the seismic frequency of the tides combined with the barometric pressure, confining our attention to the stronger or larger earthquakes, which originated in the vicinity of Tokyo or off the north-eastern coast of the Main Island. The times of the high or low waters of the tide given in the subsequent tables, relate to the tide-gauge station of Reigan-jima, Tokyo, and are practically identical to those for Yokohama. The tidal movements along the north-eastern coast of the Main Island take place some half an hour earlier than those at Tokyo and Yokohama.

11. ***Stronger earthquakes originating from the Izu island zone.*** Table IX is a list of the 14 recent stronger submarine earthquakes, which originated along the Fuji volcanic chain, namely, from among the Izu islands or in the vicinity of Hachijo, Ogasawara (Bonin), and other islands some distance off the coast of Izu peninsula; the moment of the high or low water at Reigan-jima (Tokyo) nearest to the time of occurrence of each earthquake being also given for the sake of comparison.

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* §§ 8 and 9 are translations of my notes in Japanese published in the "Toyo Gakugei Zasshi," Dec. 1906.

TABLE IX.—LIST OF THE RECENT STRONGER SUBMARINE EARTHQUAKES WHICH ORIGINATED ALONG THE FUJI VOLCANIC CHAIN.

(i) Date.	(ii) Time of Eqke. Occurrence.	(iii) Time of High or Low water at Reigan-jima (Tokyo).		Time Difference (ii)-(iii).
April 16, 1890.	9h 30m pm.	9h 18m pm.	Low water.	0h 12m
Feb. 12, 1896.	6 38 am.	4 43 am.	High water.	1 55
May 7, "	2 37 pm.	1 51 pm.	"	0 46
Jan. 18, 1897.	9 27 "	0 38 am. (next day).	Low water.	—
March 27, 1898.	3 24 am.	2 59 am.	"	0 25
Jan. 31, 1900.	2 38 "	0 23 "	"	2 15
Nov. 5, "	4 41 pm.	3 45 pm.	High water.	0 56
" 9, "	2 55 am.	1 29 am.	Low water.	1 26
" 19, "	10 59 pm.	10 30 pm.	"	0 29
Feb. 20, 1902.	10 50 am.	10 44 am.	"	0 06
June 3, 1903.	0 28 pm.	11 36 "	High water.	0 52
Nov. 13, 1904.	9 49 am.	8 55 "	"	0 54
June 7, 1905.	2 40 pm.	3 03 pm.	Low water.	−0 23
May 4, 1907.	5 37 "	4 43 "	"	0 54

With regard to the diurnal variation of the barometric pressure, the times of the earthquakes tabulated above may be grouped, except the 2nd and the last, as follows:—

(*A*).....	9 30^m pm. 9 27 „ 10 50 „	(*C*).....	2^h 37^m pm. 4 41 „ 0 28 „ 2 40 „
(*B*).....	10 50 am. 9 49 „	(*D*).....	3 24 am. 2 38 „ 2 55 „

The two groups *A* and *B* occurred at the hours of the barometric maximum, while the two other groups *C* and *D* occurred at the hours of the barometric minimum.

The difference between the time of earthquake occurrence and the nearest moment of the high or low water of the tide varied, except in the case of the 4th earthquake, between 0h 12m and 2h 15m, giving the average value of 50m. This is to be regarded as the interval by which the different earthquakes followed, except in one case, the high or low water in the Tokyo Bay, which happens not much apart in time from that along the islands of the zone in question.

12. ***Recent strong earthquakes felt in Tokyo.*** In § 8 I have considered some of the great destructive earthquakes in Japan in relation to weather. Turning now our attention to the recent earthquakes felt in Tokyo, we have 14 cases, in which the motion was strong or severe; amongst others, the shock (No. 7) of June 20, 1894, was semi-destructive and caused a considerable amount of damage. The relation of their times of occurrence to the low or high water epoch of the tide and the barometric pressure is shown in the following table.

TABLE X.—LIST OF STRONG EARTHQUAKES FELT IN TOKYO.

(h)....High water; (l)....Low water.

No.	Date.	Time of Earthquake Occurrence.	Time of High or Low Water at Reigan-jima, Tokyo Bay.	Barometric Pressure. (With sea-level and freezing point corrections).
		h m	h m	
1	Feb. 22, 1880.	0 49 am.	2 08 am. (h)	**Min.** 754.6 mm. Pressure rose after the shock.
2	Oct. 15, 1884.	4 21 am.	2 00 am. (h)	**Min.** 754 mm, at 4 pm., on 14th.
3*	Jan. 15, 1887.	6 51 pm.	9 48 pm. (h) 3 36 pm. (l)	**Min.** 754 mm, at 2 am., on 15th.
4*	April 29, 1888.	10 00 am.	7 13 am. (h) 1 25 pm. (l)	Bar. height=759 mm, pressure decreasing.
5	Feb. 18, 1889.	6 09 am.	7 04 am. (h)	**Min.** 746 mm, at 2 pm., on 17th.
6*	Dec. 24, 1891.	5 30 am.	5 07 am. (l)	Bar. height=762 mm, pressure increasing.
7*	June 20, 1894.	2 04 pm.	0 42 pm. (l)	**Min.** 754.7 mm, at 3–8 pm., on 20th.
8	Jan. 18, 1895.	10 48 pm.	10 49 pm. (h)	**Min.** Mean pressure on 18th=752.6 mm.
9	April 23, 1901.	3 10 am.	3 23 am. (l)	On 23rd, Min. 757 mm, at 4 am., Pressure increasing
10	June 23, 1902.	7 43 am.	6 31 am. (h)	**Min.** 741.5 mm, at 7 am, on 24th.
11	Feb. 24, 1906.	9 14 am.	6 57 am. (h)	Mean pressure on 24th=759 mm. Barometer ascending.
12	June 11, 1907.	8 59 am.	4 29 am. (h) 1 16 pm. (l)	**Min.** 746 mm, at 10 pm., on 13th.
13	Sept. 22, 1907.	4 50 am.	5 27 am. (h)	Pressure in the normal condition. Bar. height=756 mm at 6 am., on 22nd.
14*	Nov. 22, 1907.	2 17 am.	2 06 am. (l)	**Max.** 774 mm, at 6 am., on 22nd.

* Earthquakes of inland origin.

With regards to the atmospheric pressure, it is a notable fact that 8 out of the 14 earthquakes were accompanied by the marked depression of 741.5 to 754.7 mm. and one by a very high pressure of 774 mm; there being only 5 earthquakes which

occurred when the pressure was in the normal condition, between 756 and 762 mm. Of the 8 cases of barometric minima above noted, 4 preceded, 2 followed, and 2 were nearly simultaneous with the respective earthquakes. These relations to the atmospheric pressure of the strong and severe shocks need not necessarily be similar to those in the case of the great destructive earthquakes (§ 8).

The difference between the time of earthquake occurrence and that of the corresponding high or low water of the tide varied in 11 out of the 14 cases, between 0h 0m and 2h 21m; only in the 3 remaining cases, earthquakes happened midway between the high and low waters. Again, of the 8 earthquakes accompanied by barometric depressions, six were of submarine origin, and five of these occurred near the time of the high waters. On the other hand, of the 5 earthquakes of inland origin, three occurred with the low water and two between the low and high waters.

13. ***List of the stronger earthquakes whose origins were not much distant from Tokyo.*** The two tables XI and XII give a list of the 145 stronger earthquakes, which happened between 1902 and 1907, and whose origins were mostly in the Kwanto provinces* or off their coasts not much distant from Tokyo. The land area of disturbance of each of these earthquakes, including that in which the motion was insensible but was recorded by the ordinary Gray-Milne-Ewing type seismographs, was greater than 1,000 square *ri*. (See also the *Bulletin*, Vol. II, No. 1.) The time of the low or high water in the Tokyo Bay nearest to that of each of the earthquakes is given in the 4th column of the two tables. The different earthquakes are divided into ten groups according to the positions of their origins.

* The Kwanto provinces are Sagami, Musashi, Awa, Kazusa, Shimosa, Hitachi, etc.

TABLE XI.—STRONGER EARTHQUAKES WHOSE CENTRES WERE NOT MUCH DISTANT FROM TOKYO. INLAND ORIGIN.

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference (i)-(ii).
Group I. Musashi (eastern part excepted.)	Dec. 9, 1902	1^h 53^m am.	5^h00^m am. (l) 11 02 pm. (h) (preceding day).	h m ——
	March 13, 1903	3 04 pm.	5 23 pm. (h)	−2 19
	April 24, 1905	5 15 am.	3 33 am. (l)	1 42
	May 30, „	4 32 am.	2 33 am. (h)	1 59
	May 10, 1906	2 34 pm.	1 54 pm. (l)	0 40
	July 27, 1907	4 23 pm.	1 55 pm. (l)	2 28
	Nov. 10, „	2 03 am.	3 12 am. (l)	−1 09
	„ 22, „	2 17 am.	2 06 am. (l)	0 11
Group II. Sagami.	Jan. 17, 1902	4 18 am.	4 59 am. (l)	−0 41
	April 1, „	5 32 am.	5 03 am. (l)	0 29
	July 1, „	2 01 am.	0 40 am. (h)	1 21
	Sept. 16, „	3 19 am.	4 09 am. (h)	−0 50
	July 9, 1903	3 00 pm.	0 11 pm. (l) 5 14 pm. (h)	——
	Jan. 15, 1906	7 55 am.	8 49 am. (h)	−0 54
Group III. Western part of Hitachi, and Shimotsuke.	March 3, 1902	2 35 pm.	0 36 pm. (l)	1 59
	June 20, „	5 49 pm.	4 58 pm. (h)	0 51
	Nov. 5, „	5 49 pm.	3 00 pm. (l) 8 08 pm. (h)	——
	March 13, 1903	1 11 pm.	0 21 pm. (l)	0 50
	July 6, „	3 19 am.	2 42 am. (h)	0 37
	„ 15, „	4 51 am.	3 16 am. (l)	1 35
	„ 21, „	2 06 pm.	2 24 pm. (h)	−0 18
	April 27, 1904	3 14 am.	3 00 am. (h)	0 14
	Sept. 17, 1906	5 27 pm.	5 18 pm. (h)	0 09
	April 18, 1907	2 33 am.	2 23 am. (l)	0 10
Group IV. Kai.	May 25, 1902	8 29 pm.	7 02 pm. (h)	1 27
	Feb. 3, 1903	4 59 am.	3 27 am. (l)	1 32

TABLE XI. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference (i)-(ii).
	March 3, 1902	9^h 13^m am.	11^h13^m am. (h)	-2^h00^m
	„ 25, „	2 35 pm.	1 09 pm. (l)	1 26
	May 15, „	7 38 am.	5 57 am. (l)	1 41
	Aug. 8, „	8 37 am.	8 05 am. (h)	0 32
	Dec. 14, „	1 57 pm.	4 35 pm. (h)	−2 38
	„ 31, „	2 38 pm.	1 14 pm. (l)	1 24
	Jan. 5, 1903	8 44 am.	9 00 am. (h)	−0 16
	March 12, „	5 35 am.	4 23 am. (h)	1 12
	April 22, „	5 02 am.	7 55 am. (l)	−2 53
	May 6, „	8 52 am.	7 27 am. (l)	1 25
	June 7, „	8 38 am.	10 11 am. (l)	−1 33
	Dec. 9, „	8 55 am.	8 30 am. (h)	0 25
	March 12, 1904	6 12 am.	8 51 am. (l)	−2 39
Group V. Shimosa, vicinity of Kasumiga-ura (Hitachi), Kazusa, eastern part of Musashi.	April 4, „	8 20 am.	7 49 am. (h)	0 31
	May 8, „	7 24 am.	6 03 am. (l)	1 21
	June 30, „	8 21 am.	6 43 am. (h)	1 38
	Aug. 4, „	9 49 pm.	10 34 pm. (h)	−0 45
	Oct. 5, „	0 35 am.	1 24 am. (h)	−0 49
	April 6, 1905	9 30 pm.	6 16 pm. (h) 1 31 am. (l) (next day).	——
	May 30, „	4 32 am.	2 33 am. (h)	1 59
	June 11, „	11 51 pm.	0 12 am. (h) (next day).	−0 21
	Sept. 21, „	10 00 pm.	10 05 pm. (h)	−0 05
	„ 24, „	2 08 am.	0 50 am. (h)	1 18
	Cct. 19, „	9 10 am.	8 18 am. (h)	0 52
	Jan. 9, 1906	6 51 pm.	3 39 pm. (h) 0 42 am. (l) (next day).	——
	Feb. 18, „	2 15 pm.	11 22 am. (h)	2 53
	May 21, „	3 56 pm.	4 57 pm. (h)	−1 01
	„ 29, „	11 22 pm.	10 11 pm. (h)	1 11

TABLE XI. (*Cont.*)

Origin of Eqke .	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group V. Shimosa, Vicinity of Kasumiga-ura (Hitachi), Kazusa, eastern part of Musashi. (*Cont.*)	Aug. 21, 1906	5^h 42^m am.	5^h23^m am. (h)	0^h 19^m
	„ 22, „	0 08 am.	1 13 am. (l)	−1 05
	Oct. 6, „	6 35 pm.	6 43 pm. (h)	−0 08
	Nov. 12, „	11 07 pm.	10 03 pm. (l)	1 04
	Dec. 24, „	5 46 pm.	8 06 pm. (l)	−2 20
	Jan. 3, 1907	3 42 am.	2 39 am. (l)	1 03
	Feb. 22, „	9 57 pm.	8 02 pm. (l)	1 55
	March 13, „	0 38 am.	11 53 pm. (l) (preceding day)	0 45
	July 2, „	5 45 am.	4 32 am. (l)	1 13
	Nov. 28, „	11 28 am.	0 01 pm. (h)	−0 33
	Dec. 11, „	5 54 pm.	4 11 pm. (l)	1 43

TABLE XII.—STRONGER EARTHQUAKES WHOSE CENTRES WERE NOT MUCH DISTANT FROM TOKYO. SUBMARINE ORIGIN.

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VI. Off the coast of Hitachi.	May 17, 1902	1^h 18^m pm.	1^h50^m pm. (h)	-0^h 32^m
	Oct. 16, „	1 57 am.	4 16 am. (h)	−2 19
	Feb. 13, 1903	0 45 pm.	1 28 pm. (l)	−0 43
	July 1, „	9 10 am.	10 03 am. (h)	−0 53
	Dec. 18, „	11 20 am.	11 54 am. (l)	−0 34
	March 8, 1904	3 40 am.	4 31 am. (l)	−0 51
	Oct. 2, 1905	10 54 am.	7 26 am. (h) 2 42 pm. (l)	——
	Dec. 26, „	0 11 pm.	0 22 pm. (l)	−0 11
	Jan. 25, 1907	6 35 pm.	10 12 pm. (l) 1 02 pm. (h)	- --
	April 30, „	0 51 pm.	2 05 pm. (l)	−1 14
	May 5, „	2 16 am.	4 51 am. (l)	−2 35
	Oct. 15, „	9 05 am.	6 02 am. (l) 1 54 pm. (h)	——

TABLE XII. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VII. Off the coast of Shimosa.	Nov. 13, 1902	8^h 15^m am.	10^h06^m am. (l)	-1^h 51^m
	Oct. 27, 1904	6 24 am.	6 37 am. (h)	−0 13
	Dec. 12, „	9 56 am.	5 29 am. (h) 0 46 pm. (l)	——
	Oct. 10, 1905	10 54 am.	10 21 am. (l)	0 33
	Nov. 2, „	11 21 am.	8 45 am. (h)	2 36
	May 18, 1906	9 36 pm.	9 03 pm. (l)	0 33
	„ 19, „	1 31 am.	2 41 am. (h)	−1 10
Group VIII. Off the E. coast of Awa-Kazusa Peninsula.	July 26, 1902	7 51 am.	8 39 am. (h)	−0 48
	Jan. 31, 1903	1 47 am.	1 47 am. (l)	0 00
	March 26, „	0 59 am.	3 37 am. (h)	−2 38
	April 19, „	7 48 pm.	5 02 pm. (l) 10 36 pm. (h)	——
	July 12, 1904	7 40 pm.	4 46 pm. (h)	2 54
	„ 15, „	3 44 am.	1 39 am. (l)	2 05
	„ 16, „	10 09 am.	7 26 am. (h)	2 43
	„ 17, „	4 27 am.	3 08 am. (l)	1 19
	„ 18, „	7 51 pm.	9 29 pm. (h)	−1 38
	„ 19, „	6 20 pm.	5 03 pm. (l)	1 17
	„ 20, „	0 30 pm.	10 58 am. (h)	1 32
	Feb. 17, 1906	6 41 am.	4 20 am. (l) 9 52 am. (h)	——
	„ 23, „	6 49 pm.	5 13 pm. (h)	1 36
	„ 24, „	9 14 am.	6 50 am. (h)	2 24
	March 6, „	1 38 am.	2 48 am. (h)	−1 10
	„ 14, „	8 32 pm.	8 13 pm. (h)	0 19
	April 8, „	2 52 pm.	0 41 pm. (l)	2 11
	May 7, „	8 01 am.	3 55 am. (h) 11 27 am. (l)	——
	„ 28, „	6 59 am.	6 45 am. (h)	0 14
	Sept. 9, „	3 53 am.	3 23 am. (l)	0 30
	Oct. 19, „	9 29 pm.	5 31 pm. (h) 1 45 am. (l)	——

TABLE XII. *(Cont.)*

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii)
Group VIII. Off the coast of Awa-Kazusa Peninsula. *(Cont.)*	Nov. 11, 1906	0^h 33^m am.	11^h28^m pm. (h) (preceding day).	1^h 05^m
	„ 23, „	3 32 pm.	5 52 pm. (l)	−2 20
	Jan. 25, 1907	0 33 am.	3 26 am. (h)	−2 53
	Feb. 6, „	5 38 pm.	5 18 pm. (l)	0 20
	June 11, „	8 59 am.	4 29 am. (h) 1 16 pm. (l)	——
	„ 14, „	1 43 pm.	2 38 pm. (l)	−0 55
	Sept. 22, „	4 50 am.	5 27 am. (h)	−0 37
Group IX. Off the coast of Sagami, and outside the Tokyo Bay.	Apri 18, 1904	8 03 pm.	6 57 pm. (h)	1 06
	Jan. 8, 1906	11 00 pm.	11 50 pm. (l)	−0 50
	Nov. 7, „	11 54 pm.	6 46 pm. (h) 4 16 am. (l) (next day)	——
	Oct. 13, 1907	1 46 pm.	2 35 pm. (l)	−0 49
Group X. Tokyo Bay, and Uraga Channel.	March 12, 1902	10 48 am.	1 53 pm. (l) 6 36 am. (h)	——
	April 5, „	7 23 pm.	10 16 pm. (l)	−2 53
	„ 6, „	2 13 am.	3 30 am. (h)	−1 17
	June 23, „	7 42 am.	6 31 am. (h)	1 11
	Aug. 7, „	0 36 pm.	2 40 pm. (l)	−2 04
	Oct. 12, „	10 24 am.	7 41 am. (l) 1 38 pm. (h)	——
	Aug. 23, 1903	9 33 pm.	5 47 pm. (h) 1 05 am. (l)	——
	Oct. 27, „	9 57 pm.	9 47 pm. (h)	0 10
	Nov. 6, „	7 04 pm.	5 53 pm. (h)	1 11
	„ 10, „	6 51 pm.	3 51 pm. (l) 9 04 pm. (h)	——
	Feb. 26, 1904	5 50 pm.	7 39 pm. (l)	−1 49
	May 17, „	4 03 pm.	1 35 pm. (l)	2 28
	„ 27, „	5 41 am.	3 28 am. (h)	2 13
	„ „ „	7 46 am.	10 36 am. (l)	−2 50
	March 4, 1905	9 18 pm.	11 53 pm. (l)	−2 35
	„ 6, „	6 08 am.	5 26 am. (h)	0 42

TABLE XII. (Cont.)

Origin of Eqke.	Date.	(i) Time of Earthquake Occurrence.	(ii) Time of the High or Low Water.	Time Difference. (i)—(ii).
Group X. Tokyo Bay, and Uraga Channel. (Cont.)	July 19, 1905	5^h 03^m pm.	$7^h 11^m$ pm. (h)	-2^h 08^m
	Aug. 12, „	9 28 pm.	10 35 pm. (l)	−1 07
	Sept. 3, „	2 02 am.	2 42 am. (l)	−0 40
	Oct. 14, „	11 54 am.	0 44 pm. (l)	−0 50
	Dec. 30, „	7 53 pm.	8 24 pm. (h)	−0 31
	Jan. 9, 1906	9 56 pm.	0 42 am. (l) (next day)	−2 46
	May 21, „	2 21 pm.	4 57 pm. (h)	−2 36
	„ 24, „	2 17 pm.	1 33 pm. (l)	0 44
	„ 30, „	9 27 pm.	11 02 pm. (h)	−1 35
	Aug. 5, „	4 53 am.	5 02 am. (h)	−0 09
	„ „ „	5 32 am.	„	0 30
	Oct. 1, 1907	6 16 pm.	7 18 pm. (l)	−1 02
	Nov. 21, „	1 32 pm.	0 33 pm. (l)	0 59

Earthquakes of Inland Origin, Groups I to IV. Groups I to IV, Table XI, include the 26 earthquakes which originated, in the regions adjacent to the plain of the lower course of the Tone-*gawa* and its tributaries, namely, in the provinces of Musashi (eastern part excepted), Sagami, western part of Hitachi, Shimotsuke, and Kai. A striking feature in the diurnal distribution of these inland earthquakes is that, with the exception of the two, which occurred between 7 and 9 pm., they have all taken place between 1 and 6 am. and 1 and 6 pm., namely, at those hours when the barometric pressure is maximum. (See also Table XIII.)

The relation of the 26 earthquakes to the phases of the tide, was as follows :—

(*a*) 11 occurred with the high tide ;

(*b*) 12 occurred with the low tide;
(*c*) 3 „ between the high and low tides.

Again of the earthquakes of (*a*) and (*b*), 17 occurred after, and 6 occurred before, the low or high water. Taking the average from the cases of these 23 earthquakes, the latter followed the high or low water by a mean interval of 31 minutes.

Earthquakes of Inland Origin, Group V. The earthquakes of Group V originated in the extensive quarternary tracts, which comprise the province of Shimosa, the vicinity of the Kasumiga-ura (Hitachi), the eastern part of the province of Musashi, and a portion of Kazusa. The positions of the origins of some of these earthquakes, all inferred from the area of disturbance and the isoseismal lines, are uncertain, and were possibly off the Pacific coast of the Awa-Kazusa peninsula.

In the diurnal distribution, the earthquakes of Group V do not show the same characteristic as those of Groups I to IV, but are similar to the submarine disturbances of Groups VI to X. Out of the 39 earthquakes, 21 occurred with the high water, 15 with the low water, and the remaining 2 between the high and low waters. Again, 23 of these earthquakes took place *before*, and 15 *after*, the high or low water.

Earthquakes of Submarine Origin. The 80 earthquakes of Groups VI to X originated off the Pacific coasts of the provinces of Hitachi, Shimosa, and Sagami, and of the Awa-Kazusa peninsula, or in the Tokyo Bay. The following table gives the hourly frequency of these earthquakes taken conjointly with those of Group V, as well as that of the inland shocks, Groups I to IV.

TABLE XIII.—DIURNAL VARIATION OF THE EARTHQUAKES OF GROUPS I to X.

Hour.	A.M. (a) Eqkes of Groups I to IV. (Inland Origin.)		A.M. (b) Eqkes of Groups V to X.		P.M. (a) Eqkes of Groups I to IV. (Inland Origin.)		P.M. (b) Eqkes of Groups V to X.	
0—1	0	14	6	28	0	10	5	24
1—2	1		4		1		5	
2—3	4		4		3		6	
3—4	3		4		2		2	
4—5	4		4		1		1	
5—6	2		6		3		5	
6—7	0	1	5	35	0	1	7	32
7—8	1		5		0		6	
8—9	0		10		1		2	
9—10	0		6		0		11	
10—11	0		5		0		1	
11—12	0		4		0		5	

As will be seen from the above table, the earthquakes of the submarine and coast origins, namely, those of Groups V to X, show a tendency of occurring more frequently between 6 and 12 am., and between 6 and 12 pm., than during the earlier hours both in the forenoon and afternoon. This is approximately the reverse of the order of occurrence of the maxima in the diurnal variation of the earthquakes of inland origin, Groups I to IV.

Of the 80 submarine earthquakes of Groups VI to X, 33 each occurred with the high and low waters, while the remaining 14 occurred between these two phases of the tide. Again, 29 of the earthquakes occurred *after*, and 38 *before*, the times of the high or low water.

TABLE XIV.—SIX-HOURLY DISTRIBUTION OF THE EARTHQUAKES.

Origin.	0–6 A.M. and 0–6 P.M.			6–12 A.M. and 6–12 P.M.		
	With High Water.	With Low Water.	Between High and Low Waters.	With High Water.	With Low Water.	Between High and Low Waters.
Inland. Groups I-IV.	9	12	3	2	0	0
Shimosa, etc. Group V.	9	8	0	12	7	2
Submarine. Groups VI-X.	15	20	0	18	13	14

From Table XIV, it will be observed that the 16 submarine and coast earthquakes of Groups V–X, whose times of occurrence were between those of the high and low waters of the tide, happened exclusively between 6 and 12 am. and between 6 and 12 pm., namely, as follows :—

6^h 35^m pm.	9^h 29^m pm.
6 41 am.	9 30 pm.
6 51 pm.	9 33 pm.
6 51 pm.	9 59 am.
7 48 pm.	10 24 am.
8 01 am.	10 48 am.
8 59 am.	10 54 am.
9 05 am.	11 54 pm.

Taking the average of these times of occurrence, irrespective of their being antemeridian or postmeridian, we obtain the value of 8h 58m, or about 9h am. and 9h pm. These hours, which correspond to those of the barometric maxima in the diurnal variation, may be taken as giving the probable time when a strong earthquake, in the region under consideration, is to take place intermediate between the high and low water epochs.

Diurnal Variation of the Seismic Frequency in relation to the Phases of the Tide. Table XV gives the diurnal variations of the earthquakes occurring with the high water and the low water, and between these two, the Groups I to X being taken together.

TABLE XV.—DIURNAL VARIATION OF THE SEISMIC FREQUENCY IN RELATION TO THE PHASES OF THE TIDE.

Hour.	Earthquakes occurring with High Water.		Earthquakes occurring with Low Water.		Earthquakes occurring between High and Low Waters.	
0—1 A.M.	4	20	2	20	0	1
1—2	3		1		1	
2—3	3		5		0	
3—4	3		4		0	
4—5	3		4		0	
5—6	4		4		0	
6—7 A.M.	3	18	1	11	1	8
7—8	3		3		1	
8—9	5		3		2	
9—10	4		0		2	
10—11	1		2		2	
11—12	2		2		0	
0—1 P.M.	1	11	4	21	0	2
1—2	2		4		0	
2—3	3		6		1	
3—4	2		1		0	
4—5	0		2		0	
5—6	3		4		1	
6—7 P.M.	2	15	2	10	3	8
7—8	4		1		1	
8—9	3		0		0	
9—10	4		5		3	
10—11	0		1		0	
11—12	2		1		1	
Sum.	**64**		**62**		**19**	

Thus the earthquakes corresponding to the low water occurred twice as frequently between 0 and 6 am. and between 0 and 6 pm., as during the remaining hours. On the other hand, the earthquakes corresponding to the high water and the middle of the high and low waters, occurred not less or more frequently between 6 and 12 am. and between 6 and 12 pm., than during the other hours. It thus seems that, on the whole, the moderate earthquakes shaking the vicinity of Tokyo tend to occur more frequently with the minimum barometric pressure and the low tide, as well as with the maximum barometric pressure and the high tide. This is in accordance with one of the principles explained in § 4.

14. ***Conclusion.*** The results obtained in the foregoing §§, which are only fragmentary notes on the secondary seismic causes, show nevertheless that these latter play a very important part in the distribution of earthquakes during the day, the year, the lunar day, etc. As these secondary causes probably determine the ultimate moment when a long-continued underground stress gives rise to a sudden disturbances, their careful study will be, in conjunction with the observation on the *fore-shocks* (see the preceding article), and the investigation on *earthquake zones*, of help in approximately predicting under favorable circumstances the earthquakes likely to happen in a given district. For an illustrative example in this connection, I may refer the reader to my preliminary note on the Formosa earthquake of March 17, 1906 (the *Bulletin*, Vol. I, No. 2). The periodicity of earthquakes, other than the diurnal and the annual, also probably depends to a great extent on the secondary causes.

On the Destructive Earthquakes in the Shinano-gawa Valley and those along the Japan Sea Coast.

By

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Member of the Imperial Earthquake Investigation Committee.

With Pls. XXIX-XXXI.

CONTENTS.

1. ***Earthquakes in the Shinano-gawa valley.*** The Zenkoji earthquake of 1847 and the Sanjo earthquake of 1828 were two great historical shocks which occurred in the Shinano-*gawa* valley. I give next a short account of these disturbances and also of the Sado-Uzen earthquake of 1833, whose origin was in the Japan Sea.

2. ***Zenkoji earthquake of 1847.*** (See Fig. 1.) The great disturbance in the 4th year of Koka, generally known as the Zenkoji Earthquake, took place on May 8, 1847, at about 9 pm., and was one of the most violent shocks which ever occurred in Japan, the total number of the killed being not less than 8,600. The region of destructive motion of the earthquake, which shook strongly the northern part of the province of Shinano, and a portion of the province of Echigo, stretched from a place some

5 km to the east of the city of Takata, on the north, to the vicinity of the town of Matsumoto, on the south. The area, which was about 2,100 sq. km, with an average width of about 32 km, run in a SWS-NEN direction for a distance of 110 km, along the main course of the Shinano-*gawa* and its tributary, the Sai-*gawa*. On the south-east, it extended along the Chikuma-*gawa*, another tributary of the Shinano-*gawa*, to the vicinity of the town of Ueda; while, on the north-east, it reached almost to the boundary of the province of Shinano and the Naka-Uonuma and Higashi-Kubiki counties of Echigo.

The protuberance of the area in question on the north was probably due to the softness of the alluvial formation of the plain of Takata. The damage was, on the other hand, comparatively light in the mountainous region between Matsumoto and Ueda, partly on account of the scarcity of population.

The region, within which the greatest amount of damage was done, was about 480 sq. km in area, with an average width of 10 km, and extended for a distance of about 50 km from the vicinity of Iiyama on the north-east, to Shinmachi on the south-west, also branching out to the town of Inariyama on the south. This area, which was situated almost entirely on the west side of the Shinano-*gawa* and Sai-*gawa*, was made up mostly of tertiary and volcanic formations, and included amongst others, the following towns and villages:—

Nagano	Almost entirely destroyed.
Inariyama	500 people killed.
Shiosaki-mura.............	1,400 (out of 1,600) houses destroyed.
Mure.	Almost entirely destroyed.
O-koma.	Do.
Nojiri....................	83 houses destroyed.

The central axis of the area of the greatest damage extended from a little west of Iiyama, through the vicinity of Mure, to the valley tract of the Sai-*gawa* at some distance to the south-west of Nagano.

The city of Nagano suffered very severely, and was almost entirely destroyed by the shock and the subsequent fires; the number of the houses overthrown being, in the town or business quarters alone, 2350, of which 2194 were burnt. In Nagano and the suburbs, there were altogether 2,452 houses destroyed by fire, there being only 191 houses which escaped both shock and flame. The number of the killed, which could be ascertained, was about 2,400; this heavy amount of casualty being, in a great measure, due to the fact that the disastrous earthquake took place when multitude of people from different parts of the country were staying at Nagano, to attend the religious festivals held at the Zenkoji. The latter, which is one of the most sacred Buddhist temples in Japan, received no material damage from the earthquake, although the huge wooden structure must have been shaken tremendously, as was indicated by the throwing down of a heavy bronze bell, about 2.6 feet in diameter and 3.6 feet in height, hung in the front verandah. Fig. 3 shows the lower portion of the bell and the scar made on the corner post by the impact of the latter; while Fig. 2 gives a front view of the temple, which is in the same condition as before the great earthquake of 1847. Both of these pictures have been taken in 1908.

A special feature of the Zenkoji earthquake was the occurrence, among the mountains of tertiary formations, of landslips whose number was not less than 44,000. Amongst others, the southern side of Mount Iwakura, which is on the Sai-*gawa*, at a distance of about 12 km to the WSW of Nagano, was destroyed,

Fig. 1. Map showing the Areas of Destructive Motion of the Zenkoji and Sanjo Earthquakes.

A .... Sanjo Earthquake of 1828. (Area of destructive motion).
B .... Uzen and Sado Earthquake of 1833.
C .... Zenkoji Earthquake of 1847. (The lightly shaded part indicates the area of destructive motion, and the densely shaded part the area of the greatest violence.)

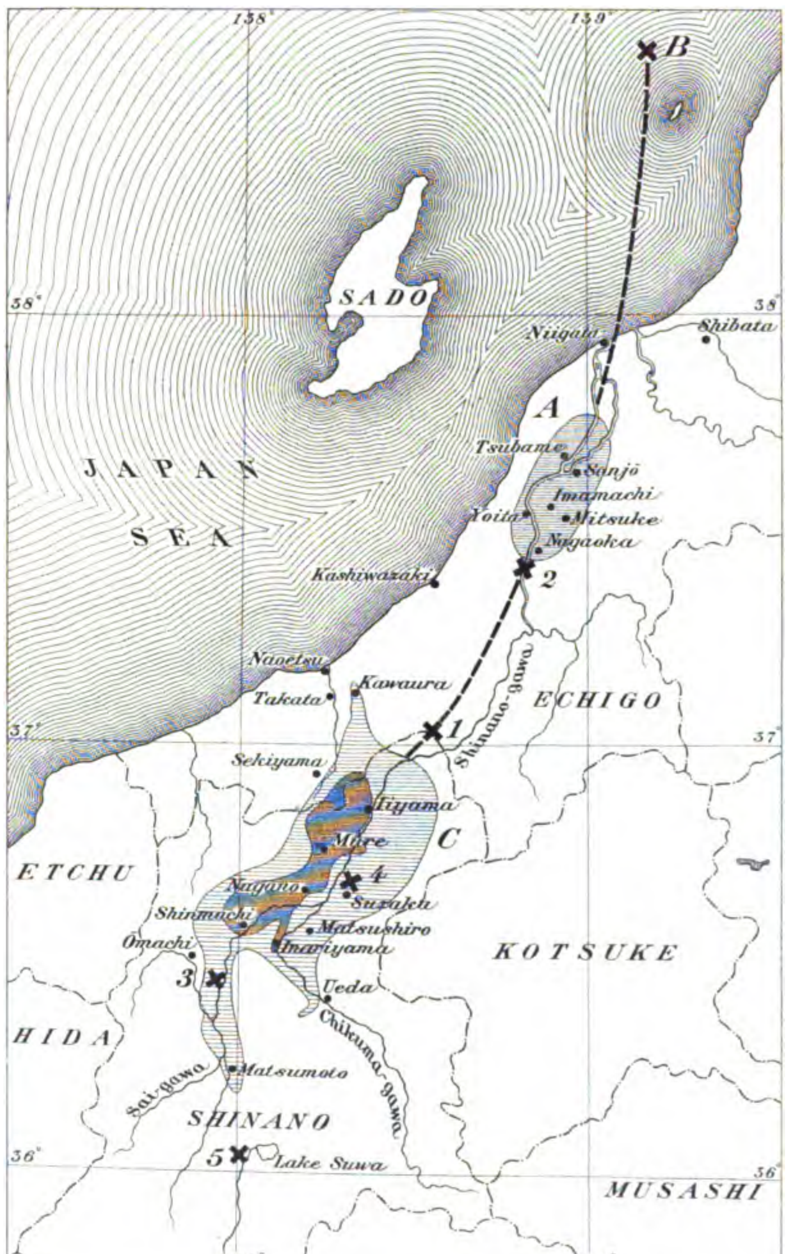
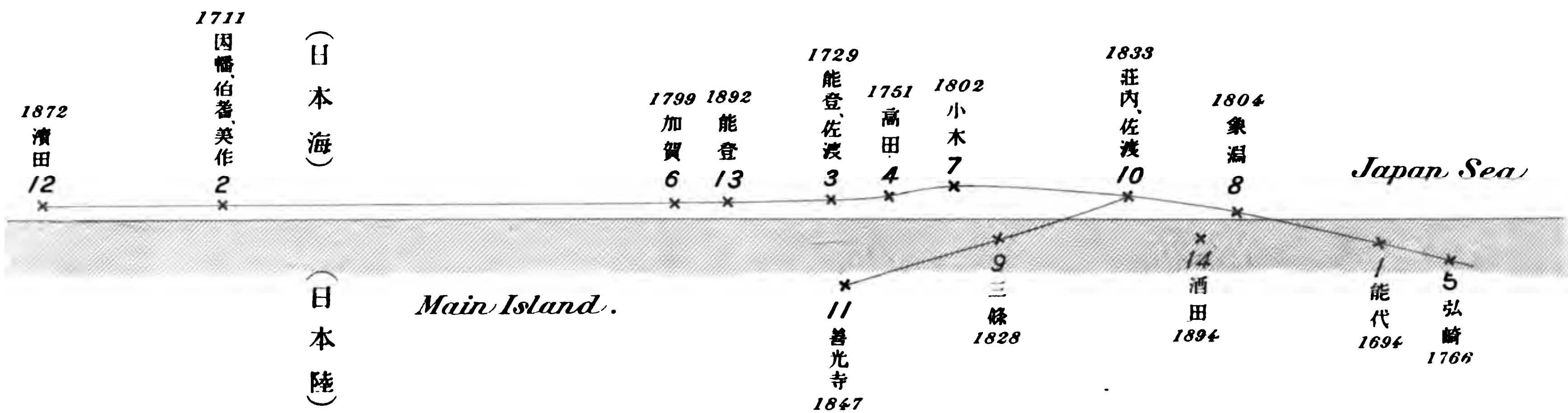


Fig. 2. The Zenkoji Temple. Front view.

Fig. 3. The Zenkoji Temple, showing the scar (indicated by a small cross ×) made on the corner post by the bell thrown down on the occasion of the earthquake of 1847.

Fig. 4. Diagram indicating the Positions of the Destructive Earthquakes in the Shinano-*gawa* Valley and along the Japan Sea Coast.



1.... Noshiro, 1694.
2.... Inaba, Hoki, and Mimasaka, 1711.
3.... Noto and Sado, 1729.
4.... Takata, 1751.
5.... Hirosaki, 1766.
6.... Kaga, 1799.
7.... Ogi (Sado), 1802.
8.... Kisagata, 1804.
9.... Sanjo, 1828.
10.... Sado and Uzen, 1833.
11.... Zenkoji, 1847.
12.... Hamada, 1872.
13.... Noto, 1892.
14.... Sakata, 1894.

resulting in two gigantic landslips which completely blocked the course of the above-named river for 20 days, and formed a lake 34 km in length and 1 to 4.3 km in width. The water finally broke the two enormous dams, and flooded over the regions along the Sai-*gawa* and Shinano-*gawa*, sweeping away a large number of the houses which escaped the destruction from the shock. The loss of human lives was, however, small, as due preparations had previously been taken to meet the emergency.

3. *Sanjo (Echigo) earthquake.* The Sanjo earthquake took place on Dec. 18, 1828, at about 8 am. The area of destructive motion was an ellipse, 50×17 km, along the lower course of the Shinano-*gawa*; the most central point of the meizoseismal region being between the towns of Sanjo and Imamachi, at about $\varphi = 37° 35'$ N, $\lambda = 138° 56'$ E. (See Fig. 1.) The total amount of the casualties was 1,443 killed and 1,749 wounded, while the numbers of the houses entirely and partially destroyed were 9,808 and 7,276 respectively, beside the 1,204 burnt. Among the towns severely affected were Sanjo, Imamachi, Mitsuke, Yoita, Tsubame, and Nagaoka, the first four having been almost entirely destroyed by the shock and the subsequent fires.

4. *Uzen and Sado earthquake.* The earthquake of Dec. 7, 1833 (4th year of Tenpo), at about 4 pm., was destructive in the island of Sado and along the coast districts of the province of Uzen. The amount of the casualties was comparatively slight, the loss of lives being about 38, in Uzen, due to the *tsunami*, or tidal waves, which followed the earthquake. The centre of the latter was submarine, its approximate postion being $\varphi = 38° 35'$ N, $\lambda = 130° 10'$ E. (See Fig. 1.)

5. *Relation of the Zenkoji earthquake to the two others.* The Sanjo earthquake took place 18 years 5 months earlier than

the Zenkoji earthquake, the meizoseismal zones of these two shocks running in nearly the same direction, namely, N40°E–S40°W. Further, the northern prolongation of the line connecting the centres of the two disturbances passes approximately through that of the Sado-Uzen earthquake. It is extremely probable that these three large earthquakes belonged to one and the same system, namely, the seismic zone formed by the Shinano-*gawa* valley and its northern prolongation. Apparently the stress reached a maximum limit along the whole extension of this zone,.. so that the Sanjo earthquake occurred first at the middle, followed 5 years later by the Sado-Uzen earthquake to the NEN, and again 13 years 5 months later by the Zenkoji earthquake to the SW; the two successive distances of the centres of the three earthquakes being each equal to about 115 km.

6. ***Relation between the former destructive and the recent strong earthquakes in the Shinano-gawa valley.*** As discussed in the *Bulletin*, Vol. I, No. 3, there were five strong semi-destructive earthquakes, which occurred along the Shinano-*gawa*, respectively in the years 1886, 1887, 1890, 1897, and 1899. The line connecting their centres has been taken as defining a seismic zone, which extends from the Koshi county in Echigo in the SW direction to the vicinity of Nagano, thence turning towards the south to the vicinity of the lake of Suwa. The approximate positions of the centres of these five earthquakes are indicated by the numerals 1, 2, 3, 4, and 5, in Fig. I. From the latter, it will be observed that the zone of the recent strong shocks is in reality identical with that of the historical destructive earthquakes. Further, the recent disturbances, Nos. 1 to 5, originated along the zone in question at those points, which are outside the area of destructive motion of the Sanjo earthquake and the meizo-

seismal region of the Zenkoji earthquake. This fact is fully in accordance with the principle that great seismic shocks never occur at one and the same centre.

7. ***Destructive earthquaks along the Japan Sea coast.*** The following is the list of the larger destructive earthquakes,* which happened within the last 2¼ centuries, on or off the Japan Sea coast and along the Shinano-*gawa* zone :—

1. Noshiro Eqke (province of Ugo); June 19, 1694, at 7 A.M.
2. Inaba, Hoki, and Mimasaka Eqke; March 19, 1711.
3. Sado and Noto Eqke; Aug. 1, 1729. Accompanied by *tsunami.*
4. Takata Eqke (province of Echigo); May 21, 1751, at 2 A.M.
5. Hirosaki Eqke („ „ Mutsu); March 8, 1766, at 6 P.M.
6. Kaga Eqke; June 29, 1799. Accompanied by *tsunami.*
7. Ogi Eqke (Island of Sado); Dec. 9, 1802, at 2 P.M.
8. Kisagata Eqke (provinces of Uzen and Ugo); July 13, 1804, at 10 P.M.
9. Sanjo Eqke (Echigo); Dec. 18, 1828, at 8 A.M.
10. Sado and Uzen Eqke; Dec. 7, 1833, at 4 P.M. Accompanied by *tsunami.*
11. Zenkoji Eqke (Shinano and Echigo); May 8, 1847, at 9 P.M.
12. Hamada Eqke (Iwami); March 14, 1872, in the evening.
13. Noto Eqkes; Dec. 9 and 11, 1892.
14. Sakata Eqke (Uzen and Ugo); Oct. 22, 1894, at 5 P.M.

Of the above 14 earthquakes, Nos. 1, 4, 5, 8, 9, 10, 11, 12, and 14 were much larger than the remaining five. Again, the five earthquakes of Nos. 1, 5, 9, 11, and 14 originated inland, while the 7 others, namely, Nos. 3, 4, 6, 7, 10, 12, and 13, originated under the Japan Sea. The origins of the two remaining earthquakes, Nos. 2 and 8, were probably also submarine. The relative

* Hokkaido and Formosa excepted.

positions of the origins of the different earthquakes are diagramatically illustrated in Fig. 4, (Pl. XXXI.)

The 14 earthquakes tabulated above may be divided, so far as their time distribution is concerned, into the following 5 groups :—

Group I.

		Year	Interval
No. 1.	Noshiro Eqke.	1694	
			17 years
No. 2.	Inaba, Hoki, and Mimasaka Eqke.	1711	
			18
No. 3.	Noto and Sado Eqke.	1729	
			22
No. 4.	Takata Eqke.	1751	
			15
No. 5.	Hirosaki Eqke.	1766	

Group II.

No. 6.	Kaga Eqke.	1799	
			3
No. 7.	Ogi „	1802	
			2
No. 8.	Kisagata „	1804	

Group III.

No. 9.	Sanjo Eqke.	1828	
			5
No. 10.	Sado and Uzen Eqke.	1833	
			14
No. 11.	Zenkoji Eqke.	1847	

Group IV.

No. 12.	Hamada Eqke.	1872

Group V.

No. 13.	Noto Eqke.	1892	
			2
No. 14.	Sakata „	1894	

The five earthquakes in Group I occurred with a tolerable regularity, the average interval being 18 years. On the other hand, the three earthquakes in Group II as well as the three in

Group III occurred at short intervals ranging from 2 to 14 years; while the interval between the 1st earthquake of Group II and the last of Group I was 33 years, and that between the 1st earthquake of Group III and the last of Group II was 24 years. Again, the time interval between the earthquake of Group IV and the last one of Group III was 25 years. These facts seem to favour the supposition that the three earthquakes of Sanjo, Sado-Uzen, and Zenkoji really belonged to one and the same seismic zone both geographically and in time distribution, as explained in § 5. All the other earthquakes, with the exception of the Sakata earthquake, belonged to the Inner Seismic Zone, which runs nearly parallel to the concave side of the Japanese islands.* The Sakata earthquake probably belonged to another system.‡

* See the "Bulletin of the Imp. Earthquake Inv. Com.", Vol. I, No. 2.

‡ The Sakata, Riku-U, and Hachinohe earthquakes have been ably studied by Professors Koto, Yamasaki, and Imamura, respectively.

Note on the Relation to the Epicentral Distance of the Duration of the Preliminary Tremor of the Earthquake Motion of near Origin.

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With Pl. XXXII.

In the Jour. Sc. Coll., Tokyo Imp. Univ., Vol. XI (1899), I have given, for the relation between the duration ($=y$) of the preliminary tremor at an observing place and the epicentral distance ($=x$) of the latter, the following equation :—

$$\overset{\mathrm{km}}{x} = 7.51\,\overset{\mathrm{sec}}{y} + \overset{\mathrm{km}}{24.9} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This equation was, in the *Publications of the Earthquake Investigation Committee*, No. 13 (1903), slightly modified into the following form :—

$$\overset{\mathrm{km}}{x} = 7.27\,\overset{\mathrm{sec}}{y} + \overset{\mathrm{km}}{38} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Both of these equations, which have been deduced from the observations of the earthquakes of x less than 1,000 km and, with a few exceptions, greater than 150 km, can not be applied to the cases of very near shocks, say, of x less than 100 km. With a view of obtaining a provisionary formula for the cases of smaller x, I have examined some of the seismograms obtained at the five Formosan meteorological observatories of Taihoku, Taichu, Tainan, Taito, and Hokoto ; the results being briefly stated in the following paragraph.

The earthquakes taken into consideration were the four destructive shocks in the years 1904 and 1906,* which I have specially studied and the positions of whose origins may be supposed to be fairly accurate. The observations were made with Omori horizontal pendulums of 6 to 10 times magnifications. The following table gives for each of the 4 shocks, the date and position of the origin of disturbance, and the epicentral distances and the durations of the preliminary tremor at the different stations.

FORMOSA EARTHQUAKES.

Date of Eqke.	Station.	Duration of Prel. Tremor $=y$ sec.	Actual Epicentral Distance $=x$ km.	Position of the Origin of Disturbance.
April 24, 1904.	Taihoku Taichu Taito Hokoto	28.7 11.4 12.8 12.7	221 98 98 90	$\varphi = 23°\,20'$ N $\lambda = 120°\,24'$ E
November 6, 1904.	Taihoku Taichu Tainan Taito Hokoto	28.8 11.2 8.3 15.5 9.0	202 76 64 117 85	$\varphi = 23°\,30'$ N $\lambda = 120°\,26'$ E
March 17, 1906.	Taihoku Taichu Tainan Hokoto	27.5 9.0 8.7 11.5	188 65 75 101	$\varphi = 23°\,35'$ N $\lambda = 120°\,32'$ E
April 14, 1906.	Taihoku Taichu Tainan Hokoto	30.6 12.0 8.6 13.0	210 88 53 98	$\varphi = 23°\,25'$ N $\lambda = 120°\,30'$ E

* See the "Bulletin of the Imperial Earthquake Inv. Com.," Vol. I, No. 2.

Arranging the epicentral distances, which varied between 53 and 221 km, and dividing these conveniently into 4 groups, we obtain :—

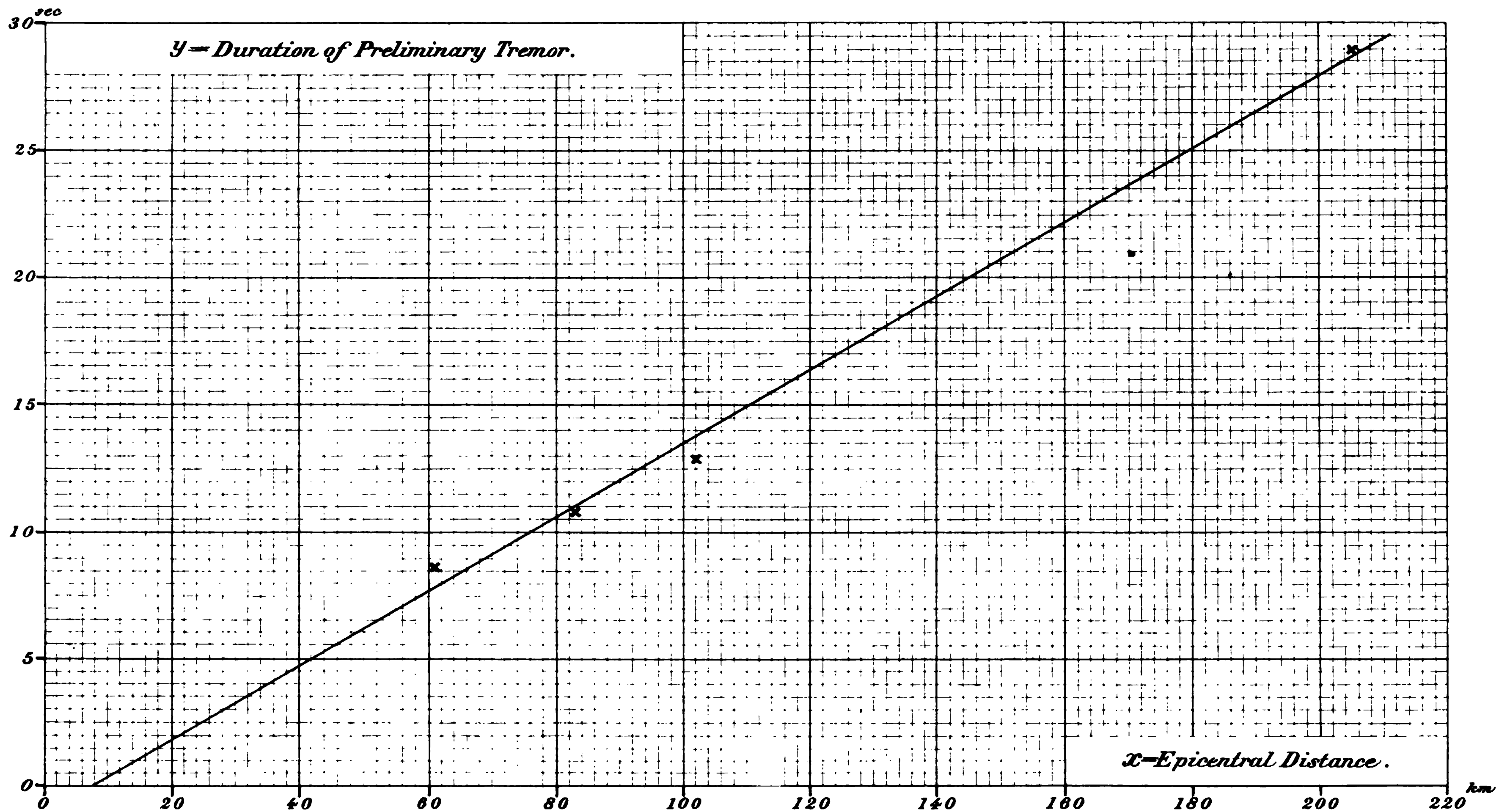
x (actual)	y	x calculated by equation (3)
221 km	28.7 sec.	
210	30.6	
202	28.8	
188	27.5	
Mean.... **205**	**28.9**	206
117	15.5	
101	11.5	
98	13.0	
98	11.4	
98	12.8	
Mean.... **102**	**12.8**	96
90	12.7	
88	12.0	
85	9.0	
76	11.2	
75	8.7	
Mean..... **83**	**10.7**	81
65	9.0	
64	8.3	
53	8.6	
Mean..... **61**	**8.6**	67

The relation between the mean values of the epicentral distance and the duration of the preliminary tremor given in the preceding table is graphically shown in the accompanying figure (Pl. XXXII). Assuming a linear equation between x and y and determining the constants from the four sets of the mean values of x and y, we obtain :—

$$x^{\text{km}} = 6.86\, y^{\text{sec.}} + 8.1^{\text{km}} \quad \ldots\ldots\ldots\ldots (3)$$

Relation between the Epicentral Distance and the Duration of the Preliminary Tremor.

(Near Earthquakes.) Formosa Observations.



The figures given in the last column of the preceding table, which have been calculated by this equation, agree closely with the actual distances.

Equation (3), which may be used under the conditions

$$50 \text{ km} < x < \text{about } 200 \text{ km},$$

seems to be more convenient for the cases of near earthquakes than Equation (1) or Equation (2); the distances calculated by the two last equations being, for a small value of y, generally larger than the corresponding actual x.

Earthquake Distributions in Formosa.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XXXIII and XXXIV.

CONTENTS.

1. ***Introduction.*** The meteorological observatory of Taihoku was first opened on Aug. 11, 1896, and the six other observatories of Taichu, Tainan, Taito, Koshun, Hokoto and Keelung, were established in the course of the next five years, namely, between 1897 and 1901. The yearly numbers of sensible earthquakes recorded at these seven stations, which are now furnished with seismological instruments, were as follows :—

TABLE I.—YEARLY NUMBERS OF SENSIBLE EARTHQUAKES RECORDED AT THE DIFFERENT METEOROLOGICAL OBSERVATORIES IN FORMOSA.

Station. / Year.	Taihoku.	Taichu.	Tainan.	Taito.	Koshun.	Hokoto.	Keelung.
1896	—	—	—	—	—	—	—
1897	7	3	9	—	—	1	—
1898	17	5	4	—	3	2	—
1899	9	10	4	—	5	2	—
1900	5	3	4	—	1	2	—

TABLE I. (*Cont.*)

Year. \ Station.	Taihoku.	Taichu.	Tainan.	Taito.	Koshun.	Hokoto.	Keelung.
1901	12	4	8	2	1	2	—
1902	13	10	12	12	5	5	6
1903	7	14	19	117*	7	6	7
1904	9	10	9	8	4	6	5
1905	12	24	8	32	3	4	5
1906	10	40*	42*	21*	11*	19*	4
1907	11	10	11	6	6	10	6
Mean.	10.2	9.3	8.8	12.0	3.9	4.0	5.5

The large yearly number for Taito in 1903 was due to the after-shocks of the strong earthquake of Sep. 7 of the same year. Similarly, the high seismic frequency in 1906 for the different stations, except Taihoku and Keelung, were due to the after-shocks of the destructive earthquakes of March 17th and April 14th in that year. These numbers, each marked in the above table by an *asterisk*, have been excluded in deducing the average values, which may be regarded as approximately giving the frequencies of the sensible seismic disturbances in the ordinary year for the seven meteorological observatories in question. It will be noticed that this frequency was about 10, namely, 8.8 to 12.0 for Taichu, Taito, Taihoku, and Tainan, but smaller and equal to about 4 for Koshun and Hokoto, and 5.5 for Keelung.

The earthquake numbers, as above described, give, however, no adequate idea of the earthquake distribution for the whole of the Island. In fact the greatest seismic activity is displayed in regions at some distances from the different meteorological observa-

tories, namely :—(1), in the vicinity of the city of Kagi, which is situated in the south-western part of Formosa and midway between Taichu and Tainan; and, (2), at the central and northern parts of the eastern coast and at the very southern extremity of the Island. Great credit is due to Mr. H. Kondo, Director-general of the Formosa meteorological observatories, who instituted in 1907 a general system of the observation of the precipitation by establishing in different parts of the Island nearly 80 stations furnished with rain-gauges, Each of these stations sends in regularly to the Meteorological Observatory of Taihoku the monthly weather report, giving amongst others the notices of the earthquakes felt. The following table, compiled from these materials, indicates the numbers of the sensible shocks in different parts of Formosa during the four years from 1904 to 1907.

TABLE II.—YEARLY NUMBERS OF EARTHQUAKES FELT AT THE DIFFERENT METEOROLOGICAL OBSERVATORIES AND RAIN-GAUGE STATIONS IN FORMOSA.

1904—1907.

Station. \ Year.		1904	1905	1906	1907	*Sum.*
天送埤	Tensohi	5	16	8	10	31
宜蘭	Giran.	19	19	23	41	79
鼻頭角	Bitokaku	2	2	2	3	7
社寮島	*Sharyoto (Keelung)	5	5	4	6	20
基隆	Keelung	1	1	2	3	5
金包里	Kinpori	0	7	4	2	9
富基角	Fukikaku	1	1	2	1	3
暖々街	Dandangai	1	1	1	0	2
火燒寮	Kashoryo	—	—	—	—	—
石底	Sekitei	8	7	8	6	21

TABLE II. *(Cont.)*

Station. \ Year.		1904	1905	1906	1907	*Sum.*
坪 林 尾	Hyorinbi	1	0	5	3	4
石 碇	Sekitei	1	1	2	4	6
屈 尺	Kussyaku	0	0	5	0	5
頂 内 埔	Chonaiho	9	4	14	7	20
臺 北	*Taihoku	9	12	10	11	45
双 峻 頭	Soshunto	0	0	3	1	1
淡 水	Tansui	2	1	2	4	7
銅 鑼 圏	Domken	0	0	4	3	3
三 角 湧	Sankakuyo	1	1	3	3	5
白 沙 岬	Hakushako	9	4	5	5	18
大 湖 口	Taikoko	1	0	2	0	1
咸 菜 硼	Kansaiho	2	4	5	3	9
内 灣	Naiwan	11	8	9	—	19
樹 杞 林	Jukirin	7	8	24	19	34
新 竹	Shinchiku	2	0	1	2	4
南 庄	Nansho	0	0	3	1	1
苗 栗	Byoritsu	4	3	6	0	7
大 湖	Taiko	1	2	14	2	5
罩 蘭	Hekiran	1	6	12	2	9
後 里 庄	Korisho	2	0	15	1	3
臺 中	*Taichu	10	24	40	10	87
水 底 寮	Suiteiryo	3	5	6	0	8
北 港 溪	Hokkokei	1	0	4	3	4
埔 里 社	Horisha	4	7	14	4	15
南 投	Nanto	9	12	14	4	25

TABLE II. *(Cont.)*

Station. \ Year.			1904	1905	1906	1907	*Sum.*
社頭	Shato		6	18	38	9	33
芦竹頭	Rochikuto		5	14	—	1	20
集々街	Shushugai		3	12	—	3	18
牛轀轆	Goonroku		8	5	13	2	15
小半天	Shohanten		3	9	29	3	15
林內	Rinnai		15	8	91	17	40
土庫	Doko		13	12	—	5	30
生毛樹	Seimoju		6	18	—	36	60
竹頭崎	Chikutok		3	19	—	65	87
嘉義	Kagi		25	33	—	19	77
達邦社	Tatsunasha		2	2	—	4	8
公田	Koden		5	8	—	10	23
鹽水港	Ensuiko		6	2	—	0	8
前大埔	Zentaiho		16	14	110	22	52
後大埔	Gotaiho		8	7	—	26	41
噍吧哖	Tabani		12	8	—	5	25
甲仙	Kosen		—	4	24	0	—
上老濃	Rono		3	0	32	2	5
南庄	Nansho	(Tainan Prefecture)	15	18	69	8	41
臺南	*Tainan		9	8	42	11	71
龜洞	Kito		13	6	26	10	29
蕃薯寮	Banshoryo		14	1	5	4	19
新威	Shin-i		4	3	20	0	7
深水	Shinsui		5	1	11	2	8
阿緱	Ako		6	1	—	5	12

TABLE II. *(Cont.)*

Station. \ Year.		1904	1905	1906	1907	*Sum.*
鳳山	Hozan	7	3	2	4	14
打狗	Takao	2	0	7	0	2
赤山	Sekizan	2	0	5	0	2
東港	Toko	3	0	7	1	4
內仔頭	Naishito	0	1	0	2	3
枋山	Bosan	0	0	0	1	1
恆春	*Koshun	4	3	11	6	26
鵞鑾鼻	Garanbi	30	17	12	11	58
九棚	Kyuho	2	4	2	0	6
牡丹社	Botansha	—	—	—	—	—
巴塱衛	Haroei	0	0	2	—	—
臺東	*Taito	8	32	21	6	79
成廣澳	Seiko-o	10	6	2	11	27
璞石閣	Bokusekikaku	3	19	0	1	23
拔仔庄	Basshisho	17	28	21	5	50
吳全城	Gozenjo	0	26	16	5	31
花蓮港	Karenko	10	50		22	82
澎湖島	*Hokoto	6	4	19	10	37
漁翁島	Gyooto.	2	0	17	0	2

2. ***Earthquake frequency in 1904.*** The seismic frequency during the year 1904 at the different places in Formosa is shown in Fig. 1 (Pl. XXXIII). From the latter there are seen to be four principal regions of seismic activity, as follows :—

(*a*) A nearly north-south zone, extending in the south-western part from the vicinity of Shato and Toroku to that of Banshoryo.

(*b*) Vicinity of Giran, near the northern end of the eastern coast.

(*c*) The eastern coast, between Karenko and Seiko-o.

(*d*) A limited portion about Cape Garanbi at the southern extremity of the Island.

Although Fig. 1 is a map showing the seismic frequency and therefore does not necessarily indicates the distribution of the origins of disturbances, the zone (*a*) seems on the whole to coincide with the main longitudinal earthquake zone in the south-western part of Formosa.* The northern prolongation of (*a*) passes approximately through the local centres at the vicinity of Jukirin and Taihoku and that of Hakushako at the north-western end of the Island. (*b*), (*c*), and (*d*) belong probably to a continuous zone, their higher seismic frequencies being due to the disturbances which occur along or off the eastern coast.

3. ***Earthquake frequency in 1904-1907.*** To obtain a general idea of the seismic distribution in Formosa for the interval, 1904 to 1907, I give in the last column of Table II the sum of the earthquakes recorded during the three years 1904, 1905, and 1907; the frequency for the year 1906 having been excluded on account of the great number of the after-shocks of the destructive disturbance, which took place on March 17th of that year. As is illustrated in Fig. 2 (Pl. XXXIV), the principal centres of the seismic activity, in which more than 50 shocks were felt during the 3 years in question, were as follows:—

(*A*) Kagi and the vicinity.

(*B*) The vicinity of Giran.

(*C*) „ „ Karenko.

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* See F. Omori: "Preliminary Report on the Formosa Earthquake of March 17, 1906." The *Bulletin*, Vol. I, No. 2.

(*D*) The vicinity of Basshisho.

(*E*) Cape Garanbi.

In broad features, Fig. 1 is similar to Fig. 2, and the local centres denoted by (*a*), (*b*), (*c*), and (*d*) in the preceding § are respectively identical with (*A*), (*B*), (*D*) and (*E*), here described. (*B*), (*C*), (*D*), and (*E*) may be regarded as forming a seismic zone which is situated on the eastern side of the axis, or main mountain chain, of Formosa, passing along the longitudinal valley separating the latter from the Taito coast range.* (*A*) forms the most active seat of seismic disturbances of inland origin.

* See also the next Article.

On the Bokusekikaku and Basshisho (Formosa) Earthquake of January 11, 1908.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XXXV and XXXVI.

CONTENTS.

1. ***Introduction.**** The disastrous earthquakes in Formosa generally occurred in the densely populated south-western part of the Island, where the ground is flat.** The different places on the eastern coast are also by no means free from the visitation of strong shocks, although the amount of the seismic damage was there always insignificant. The latter circumstance is probably due to the mountainous nature of these districts and the scarcity of inhabitants, the seismic disturbances occurring, in many cases, under the ocean. The following three earthquakes were the strongest felt in the recent years along the Pacific side of Formosa.

* The times are all given in the 1st Normal Japan Time, or that of longitude 135° E of Greenwich.

** See my paper on the Formosa earthquake of March 13, 1906. The *Bulletin*, Vol. I, No. 2.

(*a*) *Giran Eqke of June 7, 1901 ; at 9h 05m am.* The shock which was quite local, was felt strongly and caused some slight damage at the town of Giran and the vicinity :—

Giran. 5 or 6 houses had mud walls cracked, and a few roof tiles thrown down.

Shokei. One house had the roof damaged. In one case, a mud wall was thrown out of the vertical.

Hachirisha. 6 houses slightly damaged.

Suihenkyaku. 56 native houses damaged.

Taikakan. One native house destroyed.

This earthquake, which was not felt at Taito and Koshun, was *slight* at Tainan and Hokoto, *moderate* at Taihoku, and *strong* at Taichu.

(*b*) *Taito Eqke of Sept. 7, 1903 ; at 4h 14m pm.* The disturbance was felt strongly at Taito, where 92 after-shocks were recorded in the course of the following 30 days. No damage was done, the origin being sub-oceanic.

(*c*) *Karenko Eqkes of Aug. 26 and 28, 1905.* The earthquake of Aug. 26, which occurred at about 4h 52m pm., was felt slightly at Taihoku and Taichu, but insensible at Tainan, Taito, Hokoto, and Keelung. It was, however, strong at Karenko and was followed by several minor shocks. The earthquake of Aug. 28, at about 1h 23m pm., was much severer, causing at Karenko partial destruction of one ware-house and 6 native houses, besides some damage to two houses in Japanese style. This shock was also very local, the area of severe motion being limited only to the immediate vicinity of the above mentioned town. At the Gozenjo, about 10 km to the south-west of the latter, the motion was strongly felt but caused no damage. At Basshisho, about 42 km further on in the same direction, the intensity was

slight. The motion was sensible and slight at Taihoku, Taichu, and Taito, but was insensible at Tainan, Hokoto, and Keelung.

The earthquake of Jan. 11 of this year, which originated near the towns of Bokusekikaku and Basshisho in the Taito prefecture, was the strongest felt in the Island since the destructive shocks of Kagi in March and April, 1906.

Earthquake of Jan. 11, 1908.

2. ***Time of occurrence.*** The observations at the different meteorological observatories in Formosa were as follows :—

Station.	Geographical Position.		Intensity of motion.	Duration of Preliminary Tremor.	Time of Occurrence.
	Latitude (N).	Longitude (E).		sec.	h m s
Taihoku.	25° 02′	121° 31′	Moderate.	18.8 (?)	0 35 14 pm.
Taichu.	24 09	120 42	Do.	—	0 32 57 (?)
Tainan.	22 59	120 12	Strong.	18.9	0 36 14
Taito.	22 45	121 09	Do.	13.9	0 36 46
Koshun.	22 01	120 44	Moderate.	25.9	0 38 30 (?)
Hokoto.	23 32	119 33	Moderate (rather weak).	23.2	0 36 08
Keelung.	25 09	121 45	Do.	—	0 36 00
Karenko.	24 00	121 33	Strong.	—	0 36 00

The observations at the 5 stations of Taichu, Tainan, Taito, Koshun, and Hokoto, were each made with an Omori horizontal pendulum of 6 times magnification; Tainan being also furnished with an ordinary Gray-Milne-Ewing type macro-seismograph. At Taihoku the pointer of the horizontal pendulum, of 10 times magnification, got out of the smoked paper soon after the commencement of the shock, and the duration of the preliminary tremor at this place estimated from the macro-seismograph record, namely, 18.8 sec., seems to be too short. Karenko had no seismological instrument, while Keelung had simply a macro-seismograph.

The times of the earthquake occurrence at the different stations are only approximate, except that at Taihoku; the probable time of occurrence at the origin itself being about 0h 35m 00s pm.

3. *Area of disturbance.* The earthquake was sensible all over Formosa and in Hokoto (Pescadores). The shock was also felt slightly at Ishigaki-jima (Lyukyu) at an epicentral distance of about 302 km, so that the radius of the area of sensible motion was probably a little over 300 km. As shown in Fig. 2, (Pl. XXXV), the land area of moderate and strong motion was, for Formosan shocks, unusually large and had a length and breadth of 210 and 100 km respectively; the longer axis being in the direction of NEN and SWS and coinciding with the Taito longitudinal valley. Within this area, whose western boundary was formed by the line joining the cities of Toroku and Tainan, pendulum clocks were generally stopped. According to Mr. H. Kondo, who happened to be at Karenko at the time of the earthquake, the motion there was strong and lasted 25 seconds, causing the houses to be shaken considerably, although no damage was produced. At Karenko there were some after-shocks and *jinari.*

The area of severe motion, within which seismic damage was done, included the villages of Bokusekikaku, Suibi, and Basshisho, forming probably an ellipse of length and breadth respectively of about 75 and 50 km. According to the reports from the different rain-gauge stations, the shock was preceded or accompanied by sounds, in the western half of the Island, at the four places of Suiteiryo, Nanto, Doko, and Seimoju, where the intensity of motion was moderate or slight.

4. *Earthquake damage.* The villages of Bokusekikaku and Basshisho are situated among the districts inhabited by the

aboriginal tribes, whose dwellings are of the simplest construction with thatch roofing, and do not show signs of seismic damage; there being only a very few houses of "dokaku," or mud construction, prevalent among the native (old Chinese) population of Western Formosa. To these circumstances was partly due the small amount of the seismic damage to the buildings. There were at Bokusekikaku and Suibi three old houses totally overthrown, besides a number of the cases of partial destruction. Still there is no doubt that the intensity of motion in the epicentral area was much smaller than that on the occasion of the Kagi earthquake of March 17, 1906. At Suibi, the "byo" (native temple), the only *dokaku* building in the village constructed some 5 years ago, had its back wall entirely thrown down, while the damage to the front side facing S80°E was limited to cracks of the walls and the falling down of some roof tiles. (See Fig. 3, Pl. XXXVI). The walls of the sub-prefectural office at Bokusekikaku were much cracked, but the plasters did not fall down. The *dokaku* house of the chief official of the village of Chuka, constructed in the preceding year, was only cracked at the junctions of the walls. The newly built sub-prefectural office of Seiko-o was practically undamaged, except some slight separation of the timbers and walls.

Some landslips were caused by the shock in the vicinity of Basshisho, Suibi, Bokusekikaku, and Sangenya; part of the water of the river Shukoran-kei having been temporarily stopped by the falling of a soft rocky cliff. At a place about 2¼ km distant from Basshisho and among the valleys of the central mountain range the stream waters were from a similar cause stopped for a few days. Again, at Bokusekikaku and Chuka the ground was cracked, in some cases to a width of 1 foot.

5. *Approximate position of the earthquake origin.* The epicentral distances of the four meteorological observatories of Taito, Koshun, Tainan, and Hokoto, calculated by Equation (3) given on page 146 of this Number, from the durations of the preliminary tremor, are as follows :—

Station.	Epicentral Distance = x. Calculated by Equation (3), p. 146.
Taito	103^{km}
Koshun	186
Tainan	138
Hokoto	167

Drawing on the map of Formosa (Fig. 2), four circles about the different stations as centres and with radii respectively equal to the calculated epicentral distances given in the above table, we find that their points of intersection are near each other, enclosing a small quadrilateral in the vicinity of Basshisho. Taking also the isoseismal lines into consideration, the approximate position of the epicentre, marked in the figure by a small cross (×), seems to be at about

$$\begin{cases} \varphi = \ \ 23^\circ\ 37'\ \mathrm{N}, \\ \lambda = 121^\circ\ 15'\ \mathrm{E}. \end{cases}$$

The epicentre thus located is about 52 and 96 km distant respectively from Karenko and Taito, being nearer the former by 44 km. Now, by a curious coincidence, it happened that one Mr. Wakamatsu, in the service of the post office at Taito, happened to telephone to Karenko just before the occurrence of the earthquake in question. He received for answer the information that a strong earthquake was taking place at Karenko and was requested to wait for a moment; some noisy sounds being simultaneously perceived through the telephone. After a short

time interval, while he was wondering what was the matter, a strong shaking began to be felt also in Taito. This circumstance illustrates in a practical manner the fact of the transmission of the seismic waves. As the propagation velocity of the vibrations composing the principal portion of the earthquake motion is about 3.3 km per sec., the time difference between the occurrence of the shock at Karenko and that at Taito would have been about 13 seconds, for the distance difference above assumed.

6. *Relation of the earthquake of Jan. 11, 1908 to that of March 17, 1906.* The cause of the disastrous Kagi earthquake of March 17, 1906, was the formation of the Baishiko and Chinsekiryo faults, in the main direction of west-slightly-south and east-slightly-north, over a distance of 13½ km from Baishiko on the east to Dabyo on the west. It was further pointed out, firstly, that the fault was probably continued westwards to the vicinity of the town of Shinko for a further distance of about 12 km, making up a length of 25½ km; and, secondly, that this latter length corresponded only to the western half of the line of dislocation and the eastward continuation passed among the mountains for a further distance of 20 or 25 km, the total extension of the fault being some 50 km.*

From the map (Fig. 2), in which the western and the probable eastern halves of the above mentioned fault are indicated respectively by thick full and doted lines in red, the further eastward prolongation of the same line of disturbance seems to pass through the epicentre (×) of the Bokusekikaku and Basshisho earthquake of this year. My supposition is that the latter shock was a continuation of the Kagi catastrophe of 1906, the formation of the fault having been extended eastwards.

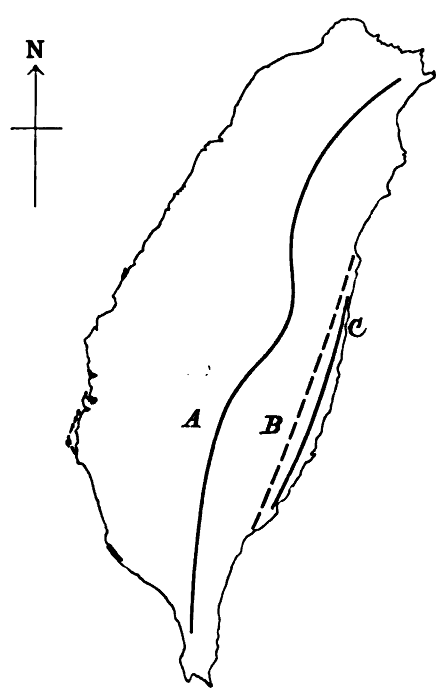
* See the *Bulletin*, Vol. I, No. 2.

If the above supposition be correct, the process of dislocation must have proceeded downwards in the eastward extension, as the focal depth of the Bokusekikaku and Basshisho earthquake was evidently great. The intensity of motion in the assumed epicentral district was not greater than in the case of the very local Karenko shock of 1905.

7. *Mutual relation of the different strong earthquakes along the eastern coast of the Island.* The back bone of Formosa, whose geographical feature is rather simple, is formed by the heavy mountain chain, which runs parallel to the longer axis, and is nearer to the eastern coast, of the Island. It begins in the Koshun peninsula at the southern extremity, and takes the NEN direction, till the great height of over 3,000 metres is reached among the peaks in the vicinity of Mt. Sylvia. Thence the direction of the range is turned toward ENE and reaches the sea at the neighbourhood of So-o; forming the tremendous steep cliffs along the eastern coast between the latter place and Karenko. Mt. Niitaka (Mt. Morrison) is the highest peak, not only in Formosa, but in the whole of Japan and attains the altitude of over 4,000 metres. The eastern side of the main

Fig. 1. Map of Formosa.

A.... General course of the Principal Mountain Range.
B.... Taito-Karenko Longitudinal Valley.
C.... Taito Coast Range.



mountain range, which is much steeper than the western side, descends abruptly into a straight longitudinal valley which extends between Karenko and Taito. To the east of this valley there is along the coast a small mountain range of about 1,000 metres height, called the Taito Coast Range. It seems probable that the Karenko-Taito longitudinal valley, whose northern and southern continuations may be supposed to run off the coast, is as explained below closely connected with the seismic phenomena in the whole eastern part of the Island. (See Fig. 1.)

Again from the maps (Pls. XXXIII and XXXIV) showing the earthquake distribution in Formosa, it seems that the more frequently disturbed regions about Giran, Karenko, Basshisho and Bokusekikaku, Taito, and Garanbi (southern extremity of the Island), belong to a continuous earthquake zone, which runs along the eastern coast of the Island, or rather along the eastern side of the main mountatin range. In the northern part, between Giran and Karenko, this zone is probably some little distance off the coast, while its middle part, between Karenko and Tainan, is probably situated inland and coincides with the Karenko-Taito longitudinal valley. The southern part of the zone, between Taito and Garanbi, is again a litle distance off the coast.

Now the Bokusekikaku-Basshisho earthquake of Jan. 11, 1908, may be taken also to belong, together with the three previous strong shocks mentioned in § 1, (*a*), (*b*) and (*c*), to the longitudinal seismic zone along the eastern coast of Formosa as above supposed. In other words, the stress was gradually increasing along the zone in question and produced strong disturbances at the different places, in the following order :—(1), Vicinity of Giran in the north ; (2), off the coast of Taito in the south ; (3), Vicinity of Karenko, between (1) and (2), but nearer to the former ; (4),

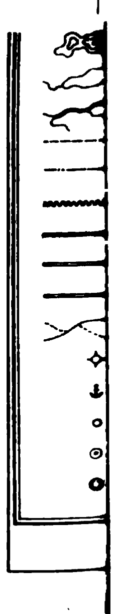


Fig. 2. The *Byo* (Temple) at Suibi, damaged by the Earthquake of Jan. 11, 1908.

vicinity of Bokusekikaku and Basshisho, between (3) and (2). (See Pls. XXXIII and XXXIV.) For other cases of the successive occurrence of strong or destructive shocks along an earthquake zone the reader is referred to the "*Bulletin*," Vol. I, Nos. 1 and 3.

8. *After-shocks.* At Basshisho the number of the after-shocks felt till 10 am. on the following day was 20 or 30, and there were several *jinari*, or earth sounds which seemed to proceed from some distance. At Bokusekikaku there were also a number of after-shocks. The following is a list of the shocks and sounds subsequent to the initial disturbance, observed by Mr. H. Kondo during his travel in the Taito prefecture :—

(January 1908)

11th.	Karenko.	Slight shock at 0.38 and 0.50 pm.
12th.	„	„ „ 0.34 pm.
13th.	Gozenjo.	„ „ 7.30 and 8.42 pm.
14th.	In the vicinity of Gozenjo.	*Jinari* at 11.25 am.
„	Bataian.	*Jinari* at 7.16 pm.
„	„	„ „ 0.09 am.
15th.	Basshisho.	Sound and slight shock at 0.54 pm.
„	Suibi.	Sound and slight shock at 8.02 pm.
„	„	Slight shock at 8.19 pm.
16th.	Sangenya.	Moderate earthquake at 6.07 pm., followed by others.
17th.	„	Moderate shock at 2 am. After the 17th, the shocks became rarer.

In conclusion I must express my thanks to Mr. H. Kondo, who have kindly put at my disposal the materials and the results of his observations respecting the earthquake.

On the Earthquakes of the Fuji Volcanic Chain.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XXXVII–XXXIX.

CONTENTS.

1. ***Introduction.*** As stated below, the submarine earthquakes of May 13, 1908 seem to have originated at a point between Cape Omaezaki (province of Totomi) and the Hachijo-jima. The latter is one of the islands belonging to the Fuji volcanic chain, and is at a distance of about 290 km due south of Tokyo. Let us first examine the relation between the activity of this chain and that of the "external seismic zone," which runs parallel to the Japan arc on the Pacific side.

2. ***Activity in recent years of the External Seismic Zone.*** The majority of the recent larger Japan earthquakes originated from the northern part of the "external seismic zone," namely, off the eastern coasts of the Main Island and the Hokkaido, ex-

tending in the south to the mouth of the Tokyo Bay. (See the *Bulletin*, Vol. I, No. 2.) Their frequency varied of course from year to year, as will be seen from the following table, which gives the annual numbers of the submarine earthquakes, whose land area of sensible motion was over 7,000 square *ri*,* and which originated from the region under consideration.

TABLE I.—YEARLY NUMBER OF THE EARTHQUAKES WHICH ORIGINATED OFF THE NORTH-EASTERN COAST OF JAPAN.

Land area of Sensible motion > 7,000 sq. *ri*.

Year.	Number of the Earthquakes.
1901	5
1902	12
1903	5
1904	3
1905	2
1906	2
1907	4

From the above table, it will be seen that the larger earthquakes of the submarine origin occurred 12 times in 1902, but were much rarer and had the average annual frequency of 2.8 in the years after 1904. This decrease of the seismic frequency for the zone in question is also clearly shown by Table II, which gives for the interval of 1892 to 1907 the yearly number of those earthquakes, each of which was felt strongly, moderately, or slightly, along the north-eastern coasts of Japan over a land area greater than 4,000 sq. *ri*.

* 1 *ri* = 2.4 miles or 3.927 km.

TABLE II.—YEARLY NUMBER OF THE EARTHQUAKES, WHICH ORIGINATED OFF THE NORTH-EASTERN COASTS OF JAPAN,

And which were each felt *strongly*, *moderately*, or *slightly* over a land area greater than 4,000 sq. *ri*.

Year.	Number of the Earthquakes.	
1892	0	
1893	1	
1894	5	
1895	1	*Mean*....**3.6**
1896	3	
1897	8	
1898	1	
1899	2	
1900	5	*Mean*....**3.6**
1901	4	
1902	6	
1903	0	
1904	2	
1905	3	*Mean*....**1.8**
1906	2	
1907	2	

According to the above table, the larger and stronger earthquakes occurred 8 and 6 times respectively in the years 1897 and 1902; the average annual frequencies during the two successive five year intervals of 1893–1897 and of 1898–1902 being each equal to 3.6. During the last 5 years, 1903–1907, the seismic activity was much smaller, the average frequency being 1.8. Thus it will be seen that the large submarine earthquakes whose origins were near Pacific coasts of the northern Japan decidedly decreased in number since 1903. It is probable that this decrease will continue for several years to come, and that

the centre of seismic activity on the outer side of Japan will be in future transferred along the "convex seismic zone" southwards to the sub-oceanic region off the coasts of Tokaido and Nankaido, between the peninsula of Izu and the Island of Kyushu. In the mean while, the activity along the Fuji volcanic zone seems to have been increasing during the recent years.

3. ***Recent activity of the Fuji volcanic zone.*** The series of the islands (see the map, Fig. 1) belonging to the Fuji volcanic chain has, within the last a few years, been unusually active in the manifestation of the subterranean energy and given rise to

na in August, probably
f 9th, 1902. The total
n number, was entirely
e.

the Minami Iwo-jima
, 1904, resulting in the
out 145 metres in height

vicinity of the Bayonnaise
na), in April, probably
outbursts continued for

about one week, a great quantity of pumice having been found floating on the sea surface.

ERRATA.

p. 167, lines 3 and 2 from bottom, *for* "strongly, moderately, or slightly," *read* "violently, strongly, or moderately."

p. 168, Table II, *for* "strongly, moderately, or slightly," *read* "violently, strongly, or moderately."

As regards the seismic activity, there were, since 1890, fifteen larger or stronger earthquakes which originated along the Fuji zone islands; the date, time of occurrence, approximate position of the origin, and area of disturbance* for each of these shocks,

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* The area of disturbance signifies here the area within which the motion was felt or recorded by the ordinary Gray-Milne-Ewing type seismographs.

numbered 1 to 16, being given in Table III. The earthquakes numbered 2′, 3′, 4′, 5′, 6′, 7′, 9′, 10′, 11′, 13′, 14′ and 15′, given for the sake of comparison, are those which do not belong to the zone in question, but which occurred within a short time interval before or after the shocks 2, 3, 4, 5, etc., respectively.

TABLE III.—LIST OF THE LARGER EARTHQUAKES WHICH ORIGINATED ALONG THE FUJI VOLCANIC ZONE. 1890–1908.

Eqkes Nos. 2′, 3′, 4′, 5′, 6′, 7′, 9′, 10′, 11′, 13′, 14′, and 15′ are the larger disturbances which preceded or followed the shocks under consideration.

No.	Date.	Approximate Position of Eqke Origin.	Time of Occurrence at Origin.	Area of Disturbance. (Longer axis × shorter axis.)
1	**April 16, 1890.**	**Vicinity of Miyake and Mikura Islands.**	**$9^h 30^m$ pm.**	**Land area of sensible motion = 4740 sq. ri.**
2	**Feb. 12, 1896.**	**In the sea of Izu.**	**6 38 am.**	**$150^{ri.} \times 120^{ri.}$**
2′	„ 14, „	Tokyo Bay.	1 58 am.	110 × 60
	„ „ „	NW. part of Musashi.	2 04 am.	110 × 65
3	**May 7, „**	**Do.**	**2 37 pm.**	**150 × 140**
3′	„ „ „	Vicinity of Kyoto.	6 38 am.	120 × 60
4	**Jan. 18, 1897.**	**In the sea of Izu.**	**9 27 pm.**	**120 × 90**
4′	„ 17, „	Suzaka (Shinano).	5 36 am.	130 × 110
5	**March 27, 1898.**	**In the sea of Izu.**	**3 24 am.**	**170 × 110**
5′	„ „ „	Off the S. coast of Sagami.	11 25 pm.	120 × 100
6	**Jan. 31, 1900.**	**In the sea of Izu.**	**2 37 am.**	**180 × 120**
6′	Feb. 1, „	Off the E. coast of Mutsu.	4 22 am.	250 × 150
7	**Nov. 5. 1900.**	**$\varphi = 33°43'$ N; $\lambda = 139°06'$ E. Near the Islands of Miyake, Mikura and Kozu.**	**4 41 pm.**	**200 × 140**
7′	„ 6, „	Off the SE. coast of Awa-Kazusa Peninsula.	6 14 pm.	120 × 80
8	**„ 9, „**	**Some distance to the South of No. 7.**	**2 54 am.**	**180 × 140**

TABLE III. *(Cont.)*

No.	Date.	Approximate Position of Eqke Origin.	Time of Occurrence at Origin.	Area of Disturbance. (Longer axis x shorter axis.)
9	**Nov. 19, 1900.**	**In the sea of Izu.**	**$10^h 58^m$ pm.**	**130 ri. x 80 ri.**
9'	" " "	N. part of Yamato.	4 40 am.	130 x 70
10	**Feb. 20, 1902.**	**Vicinity of Hachijo-jima.**	**10 50 am.**	**190 x 150**
10'	" 21, "	Off the E. coast of Mutsu.	0 35 am.	260 x 170
11	**June 3, 1903.**	**Vicinity of Hachijo-jima.**	**0 28 pm.**	**180 x 100**
11'	" 2, "	Off the E. coast of Mutsu.	7 59 pm.	150 x 90
12	**Nov. 13, 1904.**	**Vicinity of Ogasawara-jima.**	**9 49 am.**	**Land area of sensible motion = 590 sq. ri.**
13	**June 7, 1905.**	**Vicinity of Oshima.**	**2 40 pm.**	**220 x 120**
13'	" 2, "	In the Inland Sea.	2 40 pm.	450 x 200
	" 4, "	"	3 08 am.	90 x 50
	" 6, "	"	8 32 pm.	80 x 40
14	**May 4, 1907.**	**Vicinity of Ogasawara-jima.**	**5 37 pm.**	**600 x 400**
14'	" 5, "	Off the E. coast of Hitachi.	2 16 am.	220 x 180
15	**May 13, 1908.**	**Between Hachijo-jima and Omae-zaki.**	**5 23 am.**	**400 x 250**
	" " "	**Do.**	**5 37 am.**	**400 x 200**
15'	" 14, "	Central part of Hitachi.	10 57 am.	40 x 30
	" 15, "	S. part of Rikuzen.	10 40 am.	100 x 50

Of the 15 earthquakes, Nos. 1 to 15, the strongest were the three Nos. 1, 7, and 13, each of which was semi-destructive at some of the islands within the meizoseismal area, and caused some damage such as cracks of the ground, landslips of cliffs, etc. No. 1 was felt severely in the islands of Miyake and Mikura, and No. 7 in these two as well as in the island of Kozu. Eqke No. 14 originated near the island of Oshima. The positions of the origin of dis-

turbance of the 4 shocks Nos. 7, 11, 13 and 15 are indicated in Fig. 2. Of the remaining earthquakes, Nos. 10 and 11 originated in the vicinity of the Hachijo-jima, while Nos. 12 and 14 originated in the vicinity of the Ogasawara-jima.

The following table gives some of the results of the seismographical observations at Tokyo, Osaka, and Mizusawa, relating to the earthquakes Nos. 6-14. (Eqkes No. 15 are considered later on.)

TABLE IV.—EQKES NOS. 6-14, OBSERVED AT TOKYO, OSAKA, AND MIZUSAWA.

Time of Occurrence $=t$.
Total Duration of the Preliminary Tremor $=y$.
Duration of the 1st preliminary Tremor $=y_1$.
" 2nd " " $=y_2$.

No.	Date.	Tokyo.		Osaka.		Mizusawa.
		t	y	t	y	t
6	Jan. 31, 1900	2h 37m 31s am.	33s $\{y_1=15, y_2=18\}$			
7	Nov. 5, "	4 41 42 pm.	27 $\{y_1=17, y_2=10\}$			
8	" 9, "	2 55 03 am.	99 $\{y_1=56, y_2=43\}$			
9	" 19, "	10 58 39 pm.	25 $\{y_1=12, y_2=13\}$			
10	Feb. 20, 1902	10 49 25 am.	30.1	10h 50m 10s am.	103s $\{y_1=52^s, y_2=51\}$	10h 50m 22s am.
11	June 3, 1903	0 27 48 pm.	25.1	0 28 20 pm.	63	0 28 55 pm.
12	Nov. 13, 1904	9 48 50 am.	48.5	9 47 29 am.	—	—
13	June 7, 1905	2 39 30 pm.	17.	2 40 18 pm.	50	2 40 33 pm.
14	May 4, 1907	5 38 24 pm.	96.	5 38 53 pm.	—	5 38 54 pm.

Calculating, for each of Eqkes Nos. 11 and 13, the epicentral distances (x) by the formula $x^{\text{km.}}=6.86\,y^{\text{sec.}}+8.1^{\text{km.}}$,* we find:—

Eqke No. 11 ....Tokyo......180km; Osaka......440km
Eqke No. 13 ....Tokyo......125 ; Osaka......351

* This Number, p. 146.

As shown in the map (Fig. 2), the origin of Eqke No. 13, determined by the intersection of the two circles drawn about Tokyo and Osaka respectively with radii proportional to the distances here obtained, is found to be quite close to the island of Oshima, which volcano ($\varphi=34^\circ\ 43'$ N, $\lambda=139^\circ\ 24'$ E) was probably the real centre of the disturbance. The origin of Eqke No. 11 is similarly found to be about 70 km to the south-west of the island of Hachijo. The Tokyo epicentral distance of Eqke No. 7 was, according to the calculation, 193 km and its origin was probably near to Miyake-jima, approximately at $\varphi=34^\circ\ 3'$ N, $\lambda=139^\circ\ 22'$ E. These three earthquakes, together with the shock of May 13th of this year, thus seem to have originated all along the chain of the Izu volcanic islands ; the others having their centres in the same neighbourhood or southwards in the vicinity of Ogasawara-jima (Bonin Islands),

4. ***Relation between the earthquakes of the Fuji volcanic zone and those originating off the north-eastern coasts of Japan.*** According to Table III, the majority of the larger earthquakes, which belonged to the Fuji volcanic chain, and whose area of disturbance had, in each case, a longer diameter greater than 100 *ri* (=400 km), were accompanied within a day or so by similar ones originating elsewhere in Japan or off its north-eastern coasts. Before conceiving any relation between these different groups of earthquakes, however, it is necessary to examine the average frequency of larger earthquakes in the whole of Japan. This is indicated in the accompanying table, for those years in which the shocks Nos. 2, 3,........11, 13, 14 and 15 took place.

TABLE V.—YEARLY NUMBER OF LARGER EARTHQUAKES.
WHOLE JAPAN.

Year.	Number of Eqkes, whose land area of disturbance was greater than 1,000 sq. *ri*.	Number of Eqkes, whose longer axis of the area of disturbance was greater than 100 *ri* (=400 km).
1896	38	36
1897	36	34
1898	62	54
1900		72
1902		75
1903		59
1904		50
1905		84
1907		71

The annual earthquake number in Japan during the interval under consideration varied between 34 and 84, giving the average value of 59, which is equivalent to one larger shock occurring every 6.2 days. This is 7 times longer than the average interval of **21.6** hours (Table VI) between the different earthquakes of the Fuji volcanic zone and the shocks which accompanied them. Hence it is probable that the earthquakes Nos. 2′, 3′, 4′,...., which either preceded or followed the Eqkes Nos. 2, 3, 4,...., were really related to these latter.

The eleven earthquakes, 2′, 3′, 4′,....may be divided into two groups, (i) and (ii), according as they preceded or followed those of the Fuji volcanic zone, as shown in the following table.

TABLE VI.—RELATION OF THE EARTHQUAKES OF THE FUJI VOLCANIC ZONE TO THOSE OF THE OTHER ORIGINS.

Eqke. Nos.	Origin of the Eqke by which that of the Fuji Volcanic Zone was		Time interval by which Eqke of the Fuji Volcanic Zone was	
	preceded...(i)	followed...(ii)	preceded by (i)	followed by (ii)
			day hour	day hour
2′-2	....	Tokyo Bay.	....	1 19
3-3′	Vicinity of Kyoto.	....	0 8	....
4-4′	Vicinity of Suzaka (Shinano)	....	1 16	....
5′-5	....	Off the S. coast of Sagami.	....	0 20
6′-6	....	Off the E. coast of Mutsu.	....	1 2
7′-7	....	Off the SE. coast of the Awa-Kazusa Peninsula.	....	1 2
9-9′	N. part of Yamato.	....	0 18	....
10′-10	....	Off the E. coast of Mutsu.	....	0 14
11′-10	....	do.	....	0 16
13-13′	Inland Sea	....	0 18	....
14′-14	....	Off the coast of Hitachi.	....	0 9
15′-15	....	Hitachi.	....	1 5
		Mean......	0 21	0 23
			General Mean...........22 hours.	

It will be seen from the above table that there is apparently a certain regularity in the order of occurrence of larger earthquakes along the different seismic zones. All the earthquakes of Group (ii) originated off the north-eastern coasts (including Tokyo Bay) of Japan, while those of Group (i) originated in the central part of the Main Island or in the Inland Sea. Whether these interesting relations are also fulfilled in the future remains to be seen. It is true that the number of the shocks of Group (i) is too few and only four. But the uniformity of the Pacific

origin of all the 12 shocks of Group (ii) is striking. Confining our attention to the latter group alone, we may, as a provisionary conclusion, suppose that, when the seismic stress along the Japan arc reaches a maximum limit, and an earthquake first occurs along the Fuji volcanic zone, an equal or greater disturbance is likely to originate after about one day off the eastern coast of the Main Island or Hokkaido. That is to say, the Fuji zone, or the series of the islands belonging to it, forms a very sensitive seismic belt, and gives rise to the earthquake or volcanic eruption, which serves as a fore-runner to another in the northern part of the principal or external seismic zone.

5. ***Volcanic eruptions.*** Of the three volcanic eruptions mentioned in § 3, the first and the third, which occurred not very far from Izu islands group, respectively at Tori-shima and near the Bayonnaise Rock, were each accompanied by a marked seismic activity. Thus, the eruption of Tori-shima took place between the night of 7th and that of 9th, in August 1902, the larger Japan earthquakes during this epoch being as follows :—

Date. (Aug., 1902)	Approximate Time of Occurrence at Origin.	Origin of Earthquake.	Longer and Shorter axes of Area of Disturbance.
7	$0^h 36^m$ pm.	Bay of Tokyo.	$160^{ri.} \times 70^{ri.}$
„	6 22 pm.	Off the coast of Mutsu.	250×150
8	8 37 am.	Sahara (Shimosa).	200×120

It may be added that there was no large earthquake in any part of Japan during the 11 days preceding the 7th of August, and also during the 11 days succeeding the 8th of August.

The submarine eruption near the Bayonnaise Rock probably occurred between 7th and 13th of April, 1906, (i.e. simultaneously with the great outbursts of the Vesuvius), there having been the following six earthquakes during the 7 days from 4th to 14th (Formosa excepted) :—

Date. (April, 1906)	Approximate Time of Occurrence at Origin.	Origin of Earthquake.	Longer and Shorter axes of Area of Disturbance.
4	$10^{h}\ 04^{m}$ am.	Off the coast of Rikuzen.	$130^{ri.} \times 70^{ri.}$
5	11 50 am.	„ „ Iwaki.	240 × 180
6	7 29 pm.	Off the E. coast of Nemuro.	350 × ?
8	2 52 pm.	Off the E. coast of Awa-Kazusa Peninsula.	160 × 70
9	2 38 am.	Off the coast of Iwaki.	230 × 160
11	7 08 pm.	NW. part of Mino.	140 × 90

In this case again there was no large earthquake in Japan (Formosa excepted) during the 11 days preceding the 4th of April, and during the 9 days succeeding the 11th of April.

6. ***Note on volcanic earthquakes.*** The earthquakes originating along the Fuji volcanic chain are probably of the volcanic origin, that is to say, they are the effects due to the activity of the volcanic energy, resulting in the sudden formation or extension of a subterranean cavity and other disturbances. Earthquakes of this nature need not necessarily be small, and are sometimes quite different in magnitude from those, which accompany actual volcanic eruptions or explosions and which are of purely surface origins. As instances of strong volcanic earthquakes of moderate extension, I may mention the shocks on April 21st and 22nd, 1792, which preceded the final catastrophe

of the Unsen-*dake* (in the province of Hizen, Kyushu),* which caused in the town of Shimabara some damage to buildings and cracks of the ground about 1 inch in width. The earthquake of April 2, 1868, in the island of Hawaii, which attended the eruption of Mauna Loa in that year, is another example. It caused some damage to buildings in the vicinity of the mountain, in addition to a landslip which produced a remarkable mud stream. The shock at Pompeii, which had caused a considerable amount of damage to the buildings in that city 16 years prior to its final destruction by the eruption of the Vesuvius, was also evidently of the same category.

The proper volcanic earthquakes are thus sometimes strong, semi-destructive, or even locally destructive, but seem as a rule not to attain the magnitude of a large destructive shock.

Earthquake of May 13, 1908.

7. *Different shocks on May 13, 1908.* As is usually the case with stronger earthquakes of the Fuji volcanic zone, the principal shock of May 13th, 1908, at about 5h 23m am., was accompanied by many minor ones, the earliest of which occurred at 4h 44m am. on the same day. The following table is a list of 13 of the shocks of this group, which were sensible or were recorded by the ordinary Grey-Milne-Ewing type seismographs on the Main Island, during the course of the next 24 hours; the numerals within the brackets in the first column corresponding to those of the fore-shocks (Table on page 99) and after-shocks (Table X) observed at Hachijo-jima.

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* See my "Note on the Eruptions of the Unsen-dake in the 4th year of Kansei (1792)." The *Bulletin*, Vol. I, No. 3.

TABLE VII.—LIST OF THE EARTHQUAKES ON MAY 13th AND 14th, 1908, WHICH WERE SENSIBLE, OR WERE RECORDED BY THE ORDINARY GRAY-MILNE-EWING TYPE SEISMOGRAPHS.

No.	Approximate time of Occurrence at Origin.	Time of Occurrence in Tokyo.*	*Strong.*	*Moderate.*	*Slight.*	Slight (insensible) **
	[May 13th]					
	h m	h m s				
a (1)	4 44 am.	—	—	—	—	Numazu Matsumoto.
b (2)	5 06¾ am.	5 07 06 am.	—	—	—	Hachijo-jima, Numazu, Kofu, Kumagae.
c (6)	5 23 am.	5 23 22 am.	Hachijo-jima, Nagatsuro, Numazu.	Yokohama, Iida, Mera, Hamamatsu Matsumoto, Tsu, Kofu, Takayama, Kyoto.	Tokyo, Yokosuka, Hikone, Osaka, Nagoya, Gifu, Niigata.	Fukushima, Mito, Yokosuka, Fukui, Yagi, Wakayama, Tokushima, Okayama.
d	5 30 am.	—	—	Matsumoto.	Yokosuka.	Numazu.
e (7)	5 37 am.	5 37 22 am.	Hachijo-jima, Nagatsuro.	Numazu, Tsu.	Tokyo, Mera, Kofu, Nagoya.	Fukushima, Mito, Yokosuka, Gifu, Hikone, Kyoto, Osaka.
f (1′)	5 54 am.	—	—	—	Kofu.	Yokohama, Numazu.
		5 57 17 am.	—	—	Yokohama.	Yokosuka, Numazu.
g (5′)	6 34 am.	—	—	—	—	Kofu.
h (8′)	7 03¾ am.	7 04 05 am.	—	—	Kofu.	Numazu.
i (10′)	7 28 am.	—	—	—	—	Kofu.
j	8 17 am.	—	—	—	—	Kofu.
k	9 23 am.	—	—	—	—	Kofu
l	9 54 am.	—	—	—	Kofu.	Numazu.
	[May 14th]					
m	1 33 am.	—	—	—	Hachijo-jima Yokohama, Kofu.	Matsumoto, Numazu, Hikone.

* The times of occurrence in Tokyo have been taken from the seismograms furnished by the horizontal pendulum tromometer of 120 times magnification.

** A *slight* (*insensible*) shaking means an earthquake which is insensible, but is recorded by an ordinary Gray-Milne-Ewing type seismograph.

The shock at 5h 23m am. was felt *strongly* at Hachijo-jima and within an area of 110 sq. *ri* on the Main Island, which covered the major part of Izu and a portion of Totomi, causing stoppage of pendulum clocks, overflow of liquids, etc. The area of *moderate* motion, about 1,780 sq. *ri*, extended over the provinces of Mikawa, Totomi, Suruga, Kai, Sagami, Awa, and Kazusa; the total land area within which the motion was sensible or was recorded by the Gray-Milne-Ewing type seismographs being 8,640 sq. *ri*. At the Hachijo-jima itself, the second shock, which followed 14 minutes later, was felt much more strongly than the first. Again, of the 13 earthquakes tabulated above, only 8 were sensible on the Main Island. The earthquake at 5h 37m am., which was, according to the seismographic records at the different stations, of a magnitude practically equal to that of the principal shock, had a much smaller land area of disturbance than the latter. This was probably due to the removal of the origin of the second earthquake further southwards. The areas of disturbance of these two earthquakes are indicated in Pl. XXXIX.

8. ***Preliminary tremor and epicentre.*** Table VII gives the times of occurrence and the durations of the preliminary tremor of the two principal earthquakes, deduced from the records furnished by the Omori horizontal pendulum seismographs at Tokyo, Osaka, Mito, Mt. Tsukuba, Nagano, and Hachijo-jima, whose multiplication ratios varied from 10 to 300 times. The determination of the moment of commencement of the second shock was rendered uncertain by the superposition of the vibrations forming the end portion of the first.

TABLE VIII.—TIME OF OCCURRENCE AND DURATION OF PRELIMINARY TREMOR OF THE TWO PRINCIPAL EARTHQUAKES, OBSERVED WITH OMORI HORIZONTAL PENDULUMS.

Station.	Time of Occurrence. (am.)	Component.	Duration of Preliminary Tremor.	Instrument.	
				Proper Period.	Multiplication.
1st Earthquake.					
Tokyo.	$5^h\ 23^m\ 22^s$	NS	32.9 sec.	28.0 sec.	10
		,,	34.5	48.5	20
		EW	27.4	4.7	300
		,,	25.2(?)	26.5	120
		,,	24.8(?)	61.5	15
Osaka.	5 23 35	NS	46.7	30.0	20
		EW	44.8	25.0	20
		NS	42.9	4.0	90
		EW	—	4.0	90
Mt. Tsukuba.	5 23 41	EW	40.3	4.0	90
Mito.	5 22 48	EW	45.0	28.8	20
Nagano.	—	EW	39.7	13.0	20
Mizusawa.	5 24 20	—	—	—	—
Hachijo-jima.	5 19 09(?)	EW	15.2	4.5	150
2nd Earthquake.					
Tokyo.	5 37 00	NS	30.5(?)	28.0	10
		,,	32.3(?)	48.5	20
Osaka.	5 37 00	NS	46.1	30.0	20
		EW	45.7	25.0	20
		NS	48.0	4.0	90
		EW	48.5	4.0	90
Mito.	—	EW	47.0	28.8	20
Nagano.	—	EW	34.0(?)	13.0	20

The duration of the preliminary tremor at Tokyo seems to be somewhat shorter in the EW component than in the NS. As a provisionary measure I have adopted the value for the latter component, which corresponded nearly to the longitudinal wave. The duration for Osaka does not much differ in the two components, which may therefore be taken together. Table IX gives the mean durations of the preliminary tremor at the different places obtained by averaging the results relating to the two earthquakes.

TABLE IX.—MEAN DURATION OF THE PRELIMINARY TREMOR AT THE DIFFERENT PLACES.

Station.	Duration of Preliminary Tremor = y (*mean value*).	Epicentral Distance = x, calculated by Eq. (3), page 146.
Tokyo	$33.7^{sec.}$	239^{km}
Osaka	46.4	326
Mt. Tsukuba	40.3	284
Mito	46.0	323
Nagano	39.7	280
Hachijo-jima.	15.2	112

The epicentral distances (x) given in the 3rd column of the above table have been calculated from the duration (y) of the preliminary tremor by the equation $x^{km} = 6.86\ y^{sec} + 8.1^{km}$.* Drawing on the map (Fig. 4) the circles about the 6 different places as centres, with the radii proportional to the x thus obtained, the points of the mutual intersection are found to be quite close to one anothers, except those relating to Nagano. The approximate position of the epicentre marked on the map by a small cross

* This Number, p. 146.

(×), is at about $\varphi = 33° 53' N$, $\lambda = 138° 55' E$, nearly midway between the island of Hachijo and Cape Omae-zaki of Totomi. (See Fig. 3.)

9. *Fore-shocks.* The earthquake at 5h 23m am. was preceded by 5 minor precursory disturbances. These furnish a very interesting example of the occurrence of the "fore-shocks" of earthquakes, and have been discussed in another article. (This Number, p. 99.)

10. *After-shocks.* Table X gives the time of occurrence, the duration of the preliminary tremor, and the maximum range ($=2a$) of motion in the EW direction for the 12 after-shocks, which immediately followed the two principal earthquakes, the observation having been made at the meteorological observatory of Hachijo-jima with an Omori horizontal tremor-recorder of 150 times magnification.

TABLE X.—AFTER-SHOCKS OBSERVED AT HACHIJO-JIMA.

No.	Time of Occurrence at Hachijo-jima.	Total Duration.	Duration of Preliminary Tremor.	Max. $2a$.
	h m s	m s	sec.	mm
1′	5 55 02 am.	—	16.5	0.19
2′	5 57 13	5 15	16.1	0.34
3′	6 13 14	1 30	15.1	0.037
4′	6 20 46	—	—	—
5′	6 33 44	0 30	14.6	0.030
6′	6 36 55	0 50	—	0.027
7′	6 55 14	0 50	15.3	0.037
8′	7 03 55	2 00	16.3	0.090
9′	7 23 00	1 10	15.9	0.030
10′	7 28 30	0 50	16.4	0.020
11′	7 49 00	1 40	14.6	0.020
12′	8 00 40	0 30	—	0.016

Except the first two, all these shocks were very small. The duration of the preliminary tremor for the different cases varied between 14.6 and 16.5 sec., giving the average value of 15.6 sec., which corresponds to an epicentral distance of about 107 km from Hachijo-jima, probably to the NW of the latter. The successive time intervals between the 12 after-shocks were as follows :—

$2^m 11^s$	
16 01	.... (*)
7 32	
12 58	.... (*)
3 11	
18 19	.... (*)
8 41	
19 05	.... (*)
5 30	
20 30	.... (*)
11 40	

It will be observed that every alternate intervals, marked by *asterisks*, varied from about 13 to about 19 minutes and were much longer than the intermediate ones.

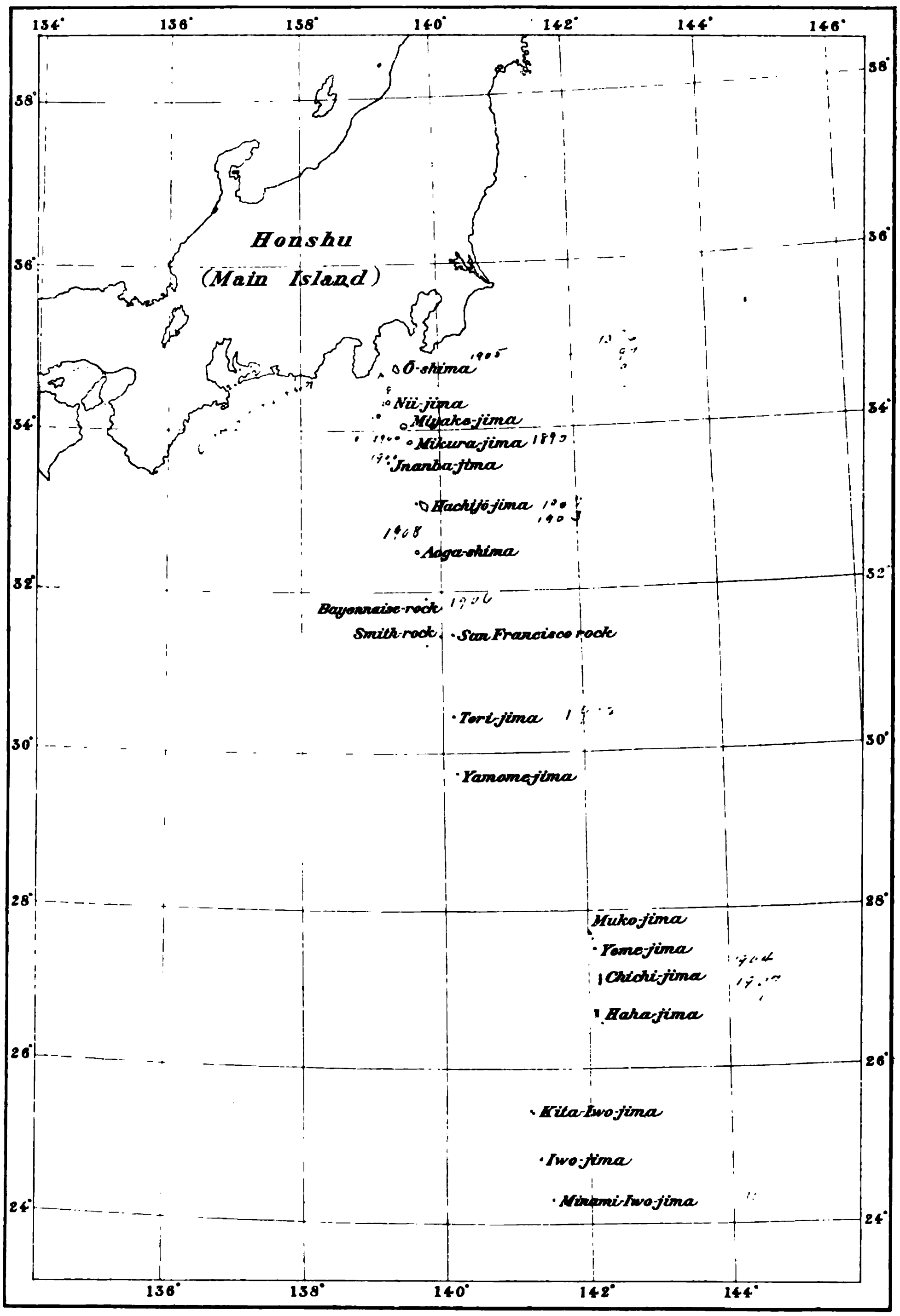
The two principle earthquakes on the 13th were followed, in accordance with the characteristic of the disturbances along the Fuji volcanic chain (§ 4), by the two following shocks which originated along the north eastern coast of the Main Island :—

May 14th : 10.57 am.......Origin, central part of Hitachi.
„ 15th : 10.40 am....... „ , S. part of Rikuzen.

There was no shock of the land area of disturbance greater than 1,000 sq. *ri* for the 8 days after the 2nd of the above earthquakes, and for 9 days 14 hours preceding the 1st shock on the 13th. (See Table III.)

Pl. XXXVII.

Fig. 1. Map of the Islands of the Fuji Volcanic Chain.



Pl. XXXVIII.

Fig. 2. Map showing the Positions of the Origins of the Earthquakes which took place along the Fuji Volcanic Zone.

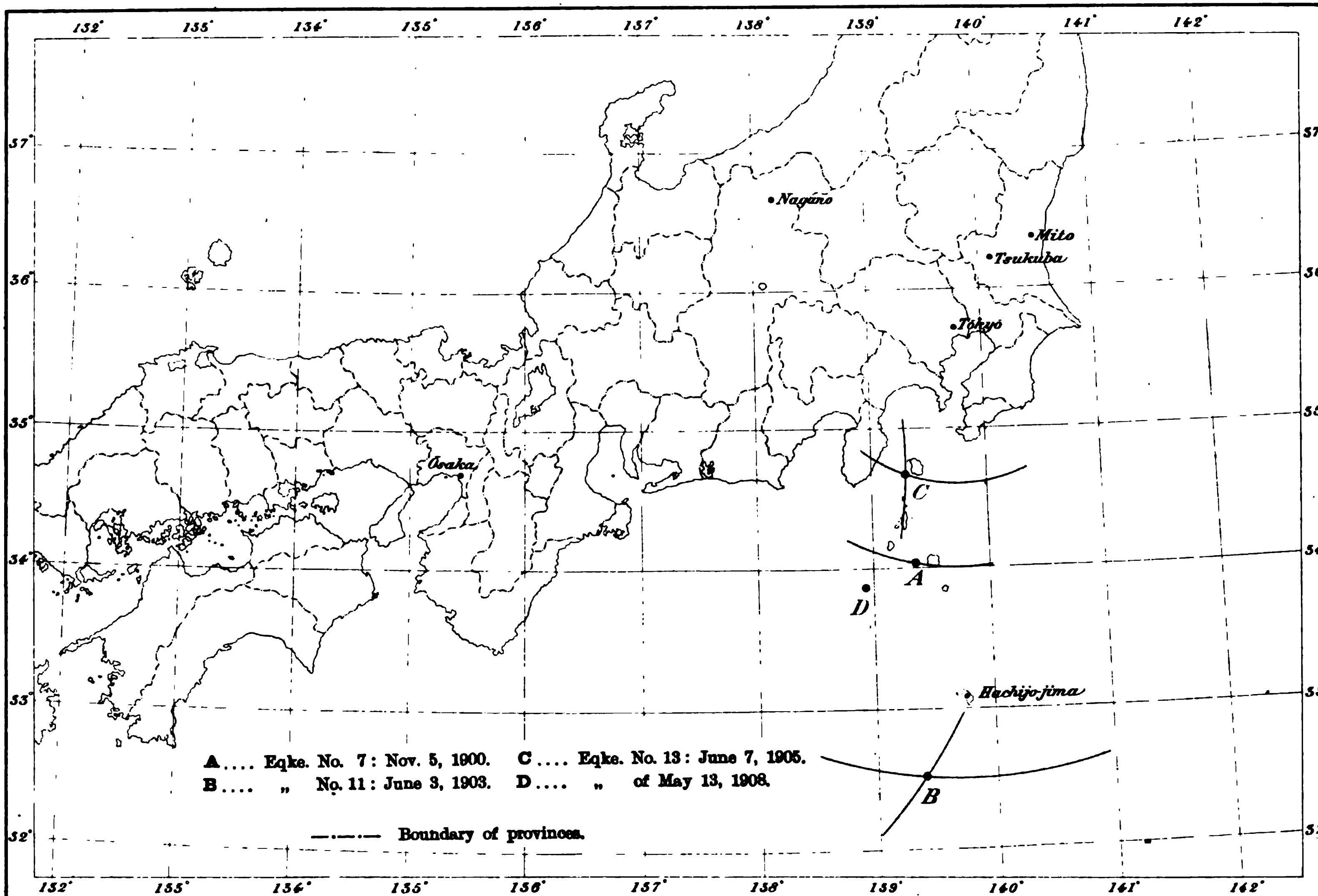
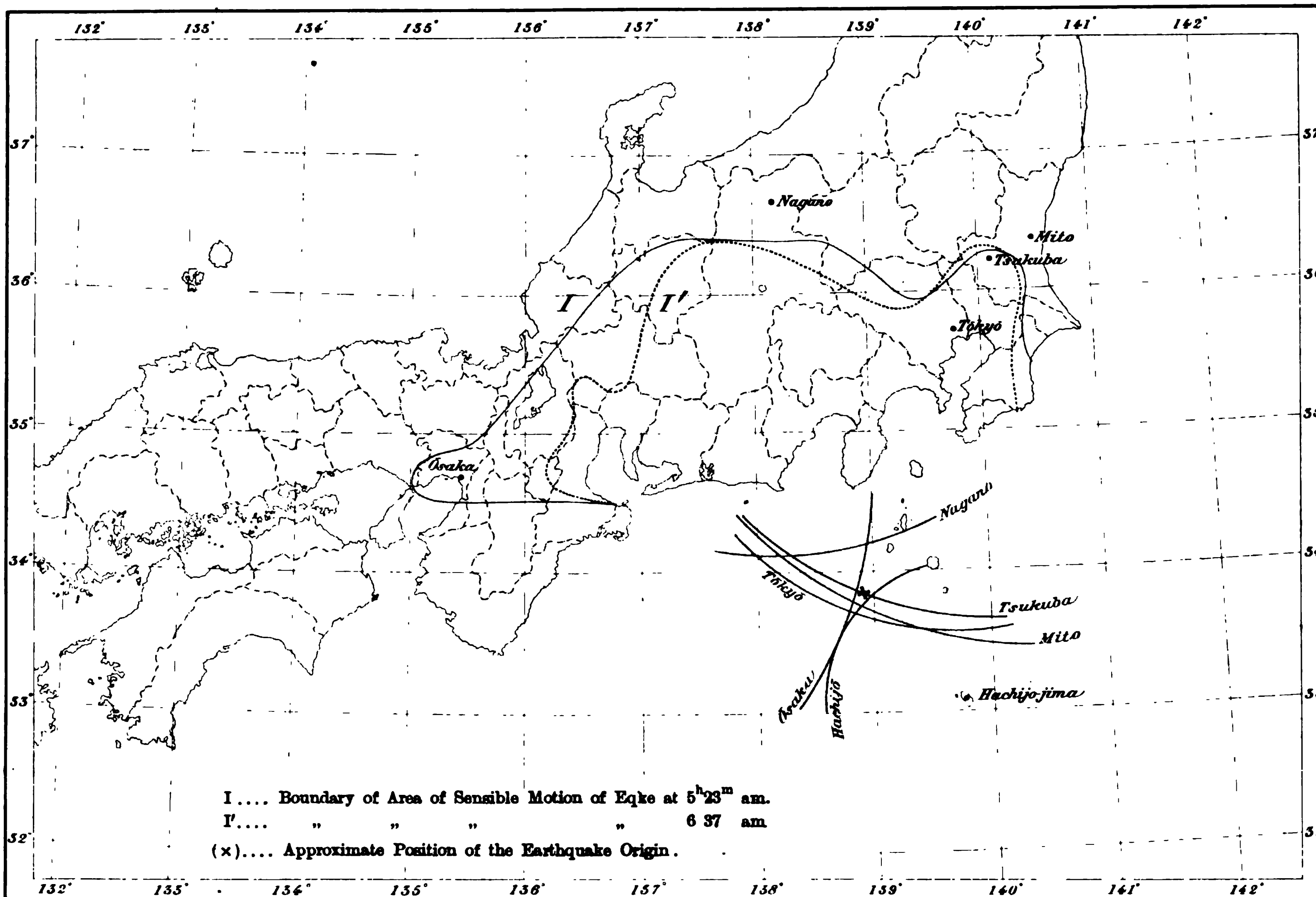


Fig. 3. Earthquakes of May 13, 1908.

—·—·— Boundary of provinces.



The After-shocks of the Zenkoji (1847) and the Tenpo (1830) Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XL and XLI.

CONTENTS.

1. ***Introduction.*** The present note gives an account of the frequency of the after-shocks of the two great Japan earthquakes of Zenkoji and Tenpo, based on the old records given in the *Dai-Nippon Jishin Shiryo* ("Material for the Earthquake History of Japan," No. 46 of the Report [Japanese] of the Imperial Earthquake Investigation Committee, 2 Vols.)

2. ***After-shocks of the Zenkoji earthquake.**** The daily number of the after-shocks of the great Zenkoji earthquake of May 8, 1847, recorded at Matsushiro by an official in the service of the feudal lord of that place are given in Tables I and II, respectively for the first 31 days and for an interval of the 42 days between Nov. 29, 1847 and Jan. 9, 1848. There were also many *jinari*, their numbers not being included in the figures of Table I. The city of Matsushiro is about 10 km to the south of the middle point of the epifocal zone.

* A short account of the Zenkoji earthquake has been given in p.p. 136-143, of this Number.

TABLE I.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. MAY 8—JUNE 7, 1847. MATSUSHIRO.

Date.	Number of Earthquakes.	Date.	Number of Earthquakes.
May 8	31	May 24	16
9	69	25	11
10	56	26	25
11	80	27	7
12	82	28	10
13	86	29	12
14	52	30	17
15	39	31	3
16	57	June 1	13
17	43	2	20
18	29	3	5
19	20	4	8
20	37	5	14
21	16	6	13
22	31	7	7
23	21	*Sum.*	**930**

TABLE II.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. NOV. 29, 1847—JAN. 9, 1848.

Date.	Earthquakes.			*Jinari.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Nov. 29	2	2	—	—	4
30	—	1	—	—	1
Dec. 1	—	3	—	—	3
2	—	4	5	—	9
3	—	3	3	1	7
4	—	2	2	—	4
5	—	2	—	—	2

TABLE II. (*Cont.*)

Date.	Earthquakes.			*Jinari.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Dec. 6	—	2	—	—	2
7	—	1	—	2	3
8	2	1	3	—	6
9	—	1	1	—	2
10	—	2	—	—	2
11	—	1	—	—	1
12	—	—	1	1	2
13	—	2	—	—	2
14	1	1	1	2	5
15	—	1	—	—	1
16	—	2	—	—	2
17	—	1	1	3	5
18	—	1	—	—	1
19	—	2	—	1	3
20	—	—	—	—	—
21	—	—	—	—	—
22	2	6	1	2	11
23	—	1	3	—	4
24	—	1	—	—	1
25	—	1	—	—	1
26	—	1	—	—	1
27	—	4	—	—	4
28	—	—	—	—	—
29	—	—	—	—	—
30	—	1	—	—	1
31	—	2	5	2	9
1848					
Jan. 1	—	2	1	—	3
2	—	—	—	—	—
3	—	1	1	—	2
4	—	1	—	2	3
5	1	4	5	(Frequent)	10
6	—	1	3	—	4
7	—	1	1	—	2
8	3	5	2	—	10
9	1	—	—	—	1
Sum.	**12**	**67**	**39**	**16**	**134**

TABLE III.—MONTHLY NUMBERS OF THE SENSIBLE EARTHQUAKES RECORDED AT THE METEOROLOGICAL OBSERVATORY OF NAGANO. 1889—1907.

Year. \ Month.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Sum.*
1889	0	1	1	0	1	0	0	0	0	1	0	0	4
1890	2	0	0	1	0	1	0	0	0	0	0	0	4
1891	0	0	0	0	1	0	1	0	0	2	1	2	7
1892	1	1	0	0	0	0	0	0	0	0	1	3	6
1893	0	1	1	0	0	0	0	0	0	0	2	0	4
1894	0	0	0	0	0	0	0	0	0	1	0	0	1
1895	2	0	0	1	0	0	0	0	0	0	0	0	3
1896	2	2	1	1	0	1	2	2	1	0	0	0	12
1897	4	2	0	5	5	2	1	1	0	0	2	1	23
1898	0	0	4	0	1	1	1	1	0	10	2	1	21
1899	1	0	4	3	1	0	1	0	0	0	2	0	12
1900	1	0	3	1	1	0	1	1	0	0	0	0	8
1901	1	0	0	0	0	1	2	2	1	0	2	3	12
1902	2	0	0	0	1	1	0	0	0	0	0	0	4
1903	1	1	1	0	0	0	2	2	0	0	0	0	7
1904	0	0	2	0	1	1	0	0	0	1	1	3	9
1905	1	1	1	1	1	2	6	2	0	3	1	0	19
1906	1	2	2	4	2	2	3	1	2	1	0	2	22
1907	0	1	1	5	4	4	2	2	0	2	1	2	24

The numbers of the after-shocks of the Zenkoji earthquake for the first 6 intervals of 5-days each commencing with May 9, the day after the great catastrophe, were, according to Table I, as follows:—

x	5-day Interval. (1847)	Observed Number of After-shocks $=y$	Calculated Number of After-shocks.
0	May 9—May 13	373	438
1	„ 14— „ 18	220	177
2	„ 19— „ 23	125	111
3	„ 24— „ 28	69	81
4	„ 29—June 2	65	63
5	June 3— „ 7	47	52

Denoting the 5-day interval and its corresponding after-shock frequency respectively by x and y, and calculating the constants of my equation for the frequency of after-shocks, we obtain from the foregoing table the following formula :—

$$y=\frac{296.4}{x+0.675} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

The values of y calculated by this equation for the different x's, given in the last columun of the above table, may be regarded on the whole to be approximately equal to the actual after-shock frequencies.

Calculating by means of Equation (1) the seismic frequency for $x=\frac{365}{5}=73$, we find :—$y=4.0$. Hence, $6y=24$ gives the probable number of the after-shocks during the one month exactly one year after the initial great earthquake, namely, during the 30 days between April 27 and May 26, 1848. The actual number of the shock during this interval was 27.

Again, calculating as a trial the seismic frequency for $x=50$ years, we find :—

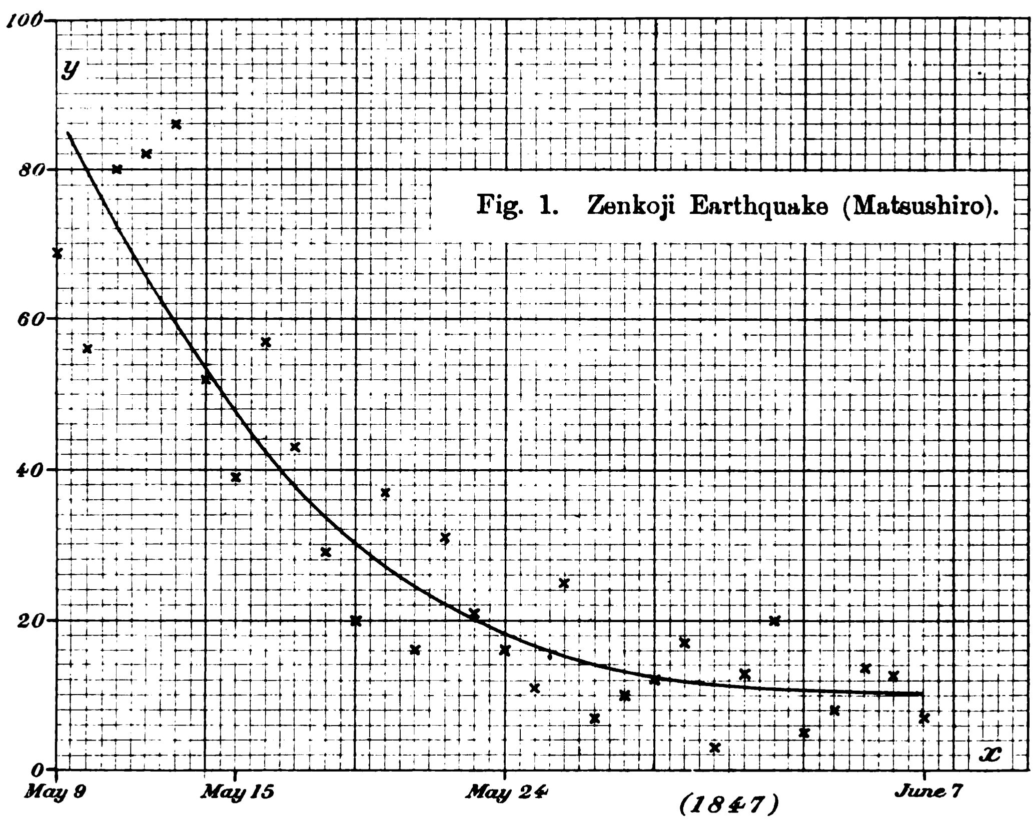
$$y=0.081\,; \quad \frac{365}{5}\times y=5.9.$$

Thus, according to Equation (1), the annual frequency (of the after-shocks only) at Matsushiro 50 years after the Zenkoji earthquake, should be approximately 6; indicating a possibility of the continuance of after-shocks of a violent and great catastrophe for over half a century. For the sake of reference, I give in Table III the yearly numbers of the sensible earthquakes recorded at the meteorological observatory of Nagano (Zenkoji) during the 19 years between 1889 and 1907. The mean of the two last named years is 1898, which is 51 years after the date of the earthquake in question, and the average annual seismic frequency during the 19 years was 10.6, which is equivalent to the sum of the yearly number of the ordinary earthquakes and that of the after-shocks, if any.

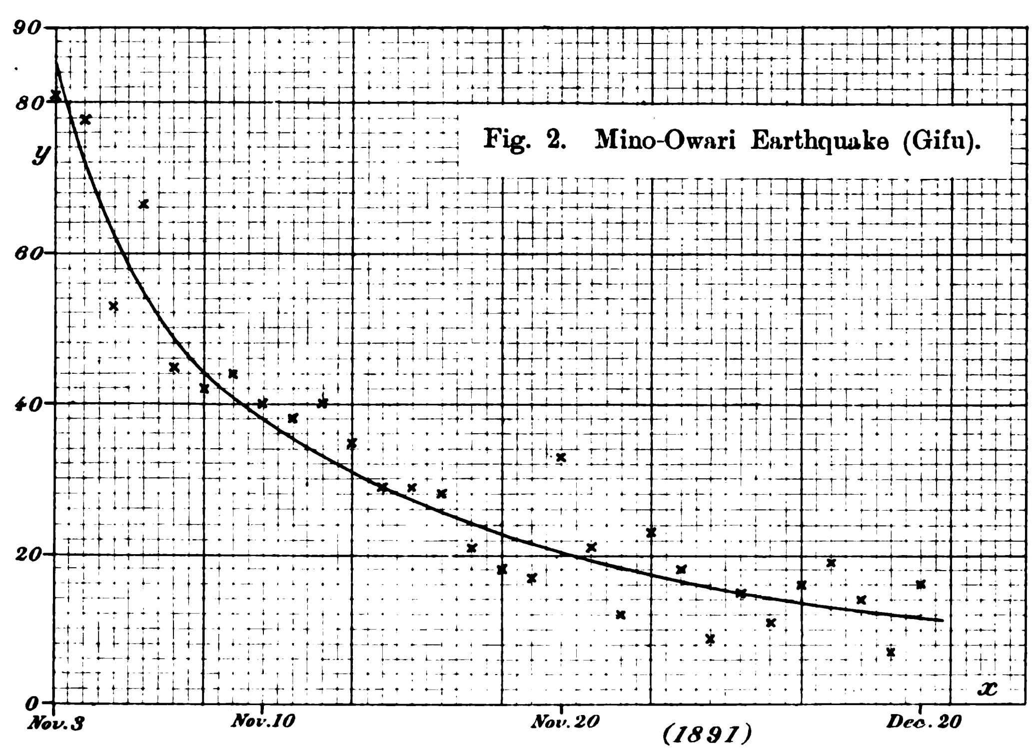
3. *Frequency of after-shocks of the Zenkoji earthquake compared with that of the Mino-Owari earthquake.* The after-shocks of the Zenkoji earthquake were more numerous than those of the Ansei earthquake of Dec. 24, 1854, recorded in Tosa, and of the Nemuro-Kushiro (Hokkaido) earthquake of March 22, 1894, recorded at Nemuro.

The following table gives the daily number of the after-shocks of the Mino-Owari earthquake for the 30 days between Nov. 3 and Dec. 2, 1891, recorded *instrumentally* at the meteorological observatory of Gifu. (The after-shocks of the Mino-Owari earthquake have been discussed in detail in the Jour. Sc. Coll., Tokyo Imp. Univ., Vol. VII, and the Publications of the Earthquake Inv. Comm., No. 7.)

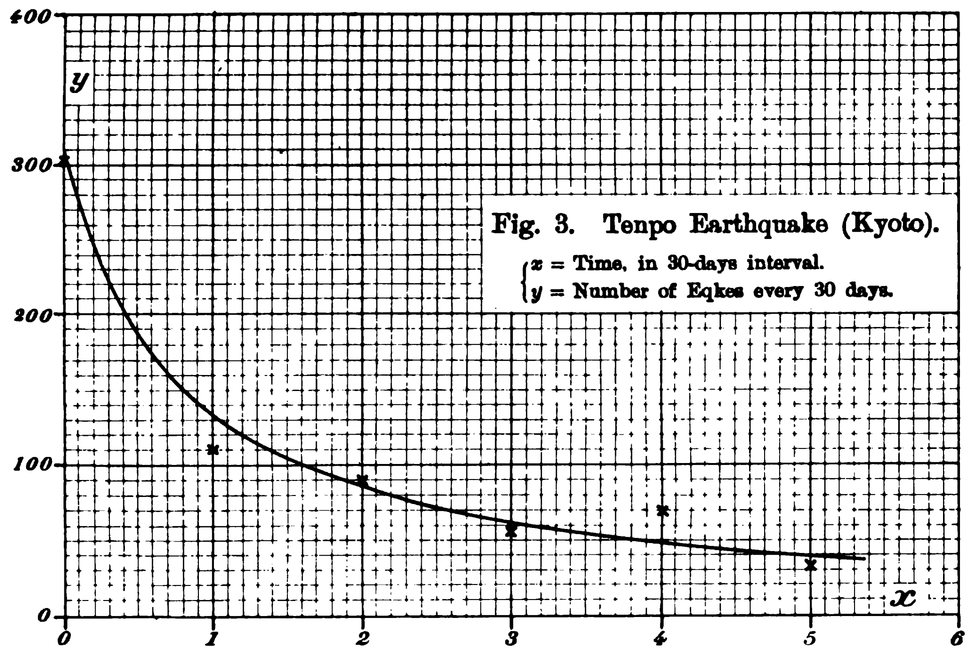
Frequency of the After-shocks.



x = Time, in Day.
y = Daily Number of After-shocks.



Frequency of the After-shocks of the Tenpo (1830) and Zenkoji (1847) Earthquakes.



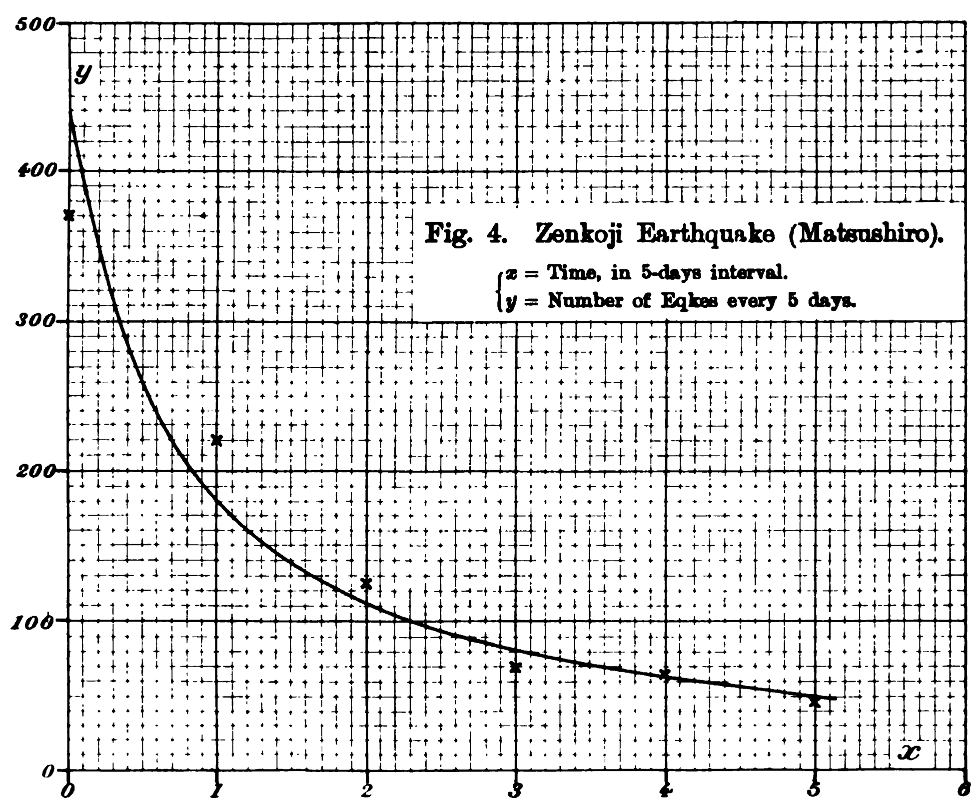


TABLE IV.—AFTER-SHOCKS OF THE MINO-OWARI EARTHQUAKE OF OCT. 28, 1891. OBSERVED AT THE METEOROLOGICAL OBSERVATORY OF GIFU. NOV. 3–DEC. 2, 1891.

Date.	Daily Number of Eqkes.	Date.	Daily Number of Eqkes.
Nov. 3	81	Nov. 19	17
4	78	20	33
5	53	21	21
6	67	22	12
7	45	23	23
8	42	24	18
9	44	25	9
10	40	26	15
11	38	27	11
12	40	28	16
13	35	29	19
14	29	30	14
15	29	Dec. 1	7
16	28	2	16
17	21		
18	18	Sum........	......**919**

The variation with time of the after-shock frequency at Gifu during the 30 days, beginning with the 6th day after the initial disturbance, is graphically shown in Fig. 2. It will be observed that the mean curve resembles in general that in Fig. 1, which indicates the similar relation for Matsushiro with respect to the Zenkoji earthquake, during the 30 days beginning with the 2nd day after the latter. Further the total numbers of the after-shocks of these two great earthquakes during the respective 30 days intervals were nearly alike, namely, 919 and about 900.

The following is a comparison of the after-shock frequencies of the two earthquakes under cosideration during the 30 days, respectively (i) 7 months and (ii) 1 year after their occurrence :—

Zenkoji Eqke.		Mino-Owari Eqke.	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(i) Dec. 1-30, 1847.	73 shocks. 12 sounds.	(i) May 28-June 26, 1892.	23 shocks. 11 sounds.
(ii) April 27-May 26, 1848.	27 shocks. numerous sounds.	(ii) Oct. 28-Nov. 27, 1892.	46 shocks. 8 sounds.

Hereby it is to be noticed that the record of the Mino-Owari after-shocks, which was made instrumentally at the meteorological observatory of Gifu, includes a number of insensible shakings and may be taken to be much more accurate than that of the old Zenkoji shocks, which was carried on without instrumental aid.

From what has been said above it seems that the number of after-shocks of the Zenkoji earthquake of 1847 was not less than that of the Mino-Owari earthquake of 1891.

4. ***After-shocks of the Tenpo earthquake of 1830.*** The earthquake of the 1st year of Tenpo (1830), on Aug. 19, which caused considerable damage in the city of Kyoto and the vicinity, was followed by numerous after-shocks whose daily numbers at Kyoto are given in Table V; their total number in the interval of 6 months up to Feb. 28, 1831, being 681. The numbers of the after-shocks during the successive intervals of 30 days, denoted by $x=0$, 1, 2, 3, 4, and 5 respectively, were as follows :—

x	30 days Interval.	Number of the after-shocks actually recorded at Kyoto $=y$.	Number of the after-shocks calculated by Equation (2).
0	Aug. 20, 1830-Sept. 18, 1830.	302	306
1	Sept. 19, „ -Oct. 18, „	111	134
2	Oct. 19, „ -Nov. 17, „	90	86
3	Nov. 18, „ -Dec. 17, „	57	63
4	Dec. 18, „ -Jan. 16, 1831.	71	50
5	Jan. 17, 1831-Feb. 15, „	33	41

The relation between the time x and the corresponding seismic frequency y, illustrated graphically in Fig. 3, is found to be as follows :—

$$y=\frac{237.9}{x+0.777} \quad \text{..............} (2)$$

The figures in the last column of the preceding table have been calculated by Equation (2). As a trial, putting $x=60\times 12=720$ (or approximately 60 years), we find $y=0.33$. Hence, $12y=4$ is the approximate calculated value of the annual seismic frequency in Kyoto, about 60 years after the earthquake in question, provided its after-shocks be supposed to have been continued for so long a time interval. Now, the value of x considered above corresponds to the year 1890, and the average annual number of earthquakes recorded at the Kyoto meteorological observatory during the 11 years between 1885 and 1895, was, as shown in the following list, approximately 5, agreeing fairly well with the result deduced from Equation (2).

YEARLY NUMBER OF EARTHQUAKES IN KYOTO. 1885–1895.

Year.	Number of Earthquakes.	Year.	Number of Earthquakes.
1885	5	1891	102*
1886	2	1892	25*
1887	6	1893	5
1888	5	1894	6
1889	2	1895	14
1890	2	*Mean.*	**5**

* The numbers for 1891 and 1892 have been omitted in taking the mean, as the majority of the disturbances in these two years were the after-shocks of the Mino-Owari earthquake of Oct. 28, 1891.

TABLE V.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE KYOTO EARTHQUAKE OF AUG. 19, 1830. KYOTO. AUG. 20, 1830—FEB. 28, 1831.

Year.	1830					1831	
Day. \ Month.	VIII	IX	X	XI	XII	I	II
1		13	4	2	3	3	2
2		11	4	6	3	0	2
3		12	2	4	3	4	2
4		11	1	1	1	4	1
5		4	1	4	2	4	2
6		2	3	2	1	2	0
7		5	3	2	1	1	1
8		6	4	1	3	2	1
9		6	9	2	3	2	3
10		5	3	6	1	3	1
11		5	3	0	2	4	2
12		6	4	7	2	2	1
13		6	4	4	2	1	0
14		12	3	5	1	2	3
15		7	4	5	1	3	3
16		3	4	1	1	4	2
17		3	1	2	2	1	3
18		3	3	3	2	0	2
19	(Great Eqke.)	3	3	2	4	0	3
20	20	1	2	0	2	0	2
21	20	11	1	1	2	0	2
22	20	4	3	1	3	0	3
23	20	1	4	2	3	1	0
24	12	2	2	2	2	0	0
25	13	3	3	3	1	0	0
26	13	9	5	3	2	1	0
27	13	6	3	2	2	0	0
28	13	6	5	2	0	0	0
29	13	1	3	2	3	2	—
30	13	4	1	2	2	2	—
31	12	—	1	—	2	2	—

5. ***Comparison between the after-shock frequencies of the Tenpo and Mino-Owari earthquakes.*** The following table gives the number of after-shocks during the successive 30 days intervals for the Tenpo and Mino-Owari earthquakes, beginning respectively with the 2nd and the 42nd days after the initial disturbances.

Tenpo Eqke of 1830 (Kyoto).		Mino-Owari Eqke of 1891 (Gifu).	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(Commencing with the 2nd day after the Earthquake)		(Commencing with the 42nd day after the Earthquake)	
$x=0$	302	Dec. 8, 1891–Jan. 6, 1892	294
1	111	Jan. 7, 1892–Feb. 5, „	110
2	90	Feb. 6, „ –March 6, „	72
3	57	March 7, „ –April 5, „	62
4	71	April 6, „ –May 5, „	73
5	33	May 6, „ –June 4, „	37

The numbers of the Mino-Owari after-shocks, which are the numbers of the earthquakes instrumentally observed at Gifu and do not include the cases of the *jinari*, or mere sounds, will thus be seen to be very nearly equal, on the whole, to the corresponding figures for the Tenpo earthquake. That is to say, the monthly after-shock frequency during the earlier epoch of the latter earthquake was practically identical with that of the former, with a time retardation of 40 days. (See Figs. 3 and 4.)

6. ***Conclusion.*** The foregoing §§ seem to indicate that the after-shocks of great earthquakes are governed by time relations which are more or less alike in the different cases. The three disturbances of Zenkoji, Tenpo, and Mino-Owari, all originated along great earthquake zones, the similarity of the causes probably tending also to the similarity of the phenomena of after-shocks.

Note on the Seismic Stability of the Piers of the Naisha-gawa Railway Bridge, Formosa.

By

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With Pls. XLII & XLIII.

In connection with the seismic experiments on the fracturing and overturning of columns, described in the "Publications of the Earthquake Investigation Committee," No. 4, I have used for the fracturing the formula

$$a = \frac{IgF}{x_0 f W},$$

in which the different symbols have the following significations:

a = Acceleration of the earthquake motion necessary for fracturing a given column, supposed to be uniform in section or else to have a vertical axis or plane of symmetry.

g = Acceleration due to the gravity = 9,800 mm/sec².

F = Tensile strength of the column at the section of fracture.

x_0 = Half width of the section of fracture in direction parallel to the earthquake motion.

f = Height of the centre of gravity of the portion above the section of fracture.

W = Weight of the fractured portion of the column.

In the practical application of the above formula to the calculation of the strength of bridge piers, chimneys, walls, etc., there is always a great uncertainty respecting the value of the tensile strength F; it being impossible that each of such masonry struc-

tures should have a perfect homogeneity of strength of material. A column is therefore broken by the earthquake shock at the weakest place near the theoretical section of fracture. Again, a brick structure of large dimensions requires a certain length of time for the hardening of the mortar joints, such that the latter would be a good deal compressed before their conversion into perfectly solid elastic bodies. From this latter circumstance it seems that, at the mortar joints, where the brick work is almost invariably broken, tension will tend to set in immediately with the bending of the column. From these considerations, I have in my former papers simply taken the tensile strength of the brick work into consideration. For certain masonry structures, however, we may more logically take the quantity F in the above equation as denoting the tensile strength of the material increased by the weight per unit area of the section of fracture of the mass above the latter; it being absolutely necessary for the practical applications of the results that the strength of the material should not be over-estimated. Let us now consider, as an example, the seismic stability of the tall piers of the Naisha-*gawa* bridge in Formosa.

The single track Naisha-*gawa* bridge on the Formosa main railway line, consists of nine 60′ plate girders supported by two abutments and eight piers of masonry (Fig. 3), with embedded iron frame. As the ground is of a soft rocky formation, there is no well sinking, the heights of the piers, including the thickness of the foundation, being as follows:—

Northern, or Taihoku-end, Abutment.	27′ 0″
No. 1 Pier	70 7
No. 2 „	92 6¼
No. 3 „	114 5

No. 4 Pier	114′ 5″
No. 5 „	114 3
No. 6 „	110 3
No. 7 „	105 0.5
No. 8 „	105 0.5
Southern, or Taichu-end, Abutment	46 9

Thus the six piers Nos. 3 to 8 are each taller than 105′, the construction in masonry of these high piers having been necessitated by the peculiar conditions of climate in Formosa, which cause iron spikes, bolts, etc. to rust quickly, and which render the maintenance in proper manner of high trestle works of iron extremely difficult.

Weakest section. In considering the seismic stability of the high piers of the Naisha-*gawa* bridge, we must first determine the approximate position of the weakest section, or the height where these structures are likely to be broken in case of a violent earthquake. If each of these piers be regarded as a "tall column," it would behave as a high brick chimney and be broken by the earthquake shock at about two-thirds of its height. If the column be, on the other hand, regarded as a "short column," then it would be weakest at, or near, the base. Thus it is first necessary to determine the length of the vibration period, which is proper to each of the columns and on which depends the classification of the latter with respect to the height of the section of fracture. The period, whose exact value can only be found from an actual measurement, may be estimated, so far as the order of magnitude is concerned, from a comparison with other bridge piers whose vibrations have been investigated. Thus for instance, the tallest of the piers of the single track Kizu-*gawa* bridge of Kwansai Railway, has a height of 60′ and supports the ends of a 200′

Pratt truss and a 100′ Warren girder. This pier stands directly on native rocks, and therefore its motion may be regarded as that due to its whole height; the periods of the transverse and longitudinal vibrations being respectively between 0.30 and 0.15 sec., and between 0.31 and 0.14 sec.* As now the bed of the Formosa river in question is rocky in nature, and not muddy, the piers of the Naisha-*gawa* bridge are to be regarded as vibrating approximately with their bases as centres; the period being, when inferred from the case of the Kizu-*gawa* bridge, probably 0.5 sec. or so., that is to say, much shorter than the period of the large destructive earthquake motion. From these considerations we may conclude that each of the high piers of the Naisha-*gawa* bridge would behave on the occasion of a destructive earthquake, not as a tall brick chimney, but is to be regarded as a "short column," and is weakest at the base.

Stability of the piers. Let us consider the stability against the earthquake motion of the two tallest piers, Nos. 3 and 4, of the Naisha-*gawa* bridge. As shown in Fig. 4, each of these two piers, rectangular in section, is 114′ 5″ in height, and is 10′ × 6′ at the top, and 22′ 11″ × 20′ 0″ at the base or the ground level; there being at the foot on the up-stream side a buttress 19′ 3½″ in height. The foundation, constructed to suit the nature of the ground, is 14′ 5″ in thickness. Further, the metal frame embedded in each of the piers consists of 8 iron rods, 1½″ in diameter, reaching from a few feet below the top down to the middle of the foundation, joined by horizontal iron bars forming a rectangle at every 10′ distance of the vertical.

Now a body of the dimensions like those of the pier under consideration can never be overturned as a whole, even when the

* See the "Publications of the Earthquake Investigation Committee," No. 12.

structure simply rests on, and not fixed to, the ground.* Hence, the question of the seismic stability of the pier reduces itself to that of the fracture, which is, when the earthquake is sufficiently violent, most likely to take place at or near the base, as before explained.

(i) Let us first calculate the strength of the pier at its base, or the section B, supposing the direction of the shock to be parallel to the length of the bridge. (See Figs. 1 and 4.)

Fig. 1.
(Section B)

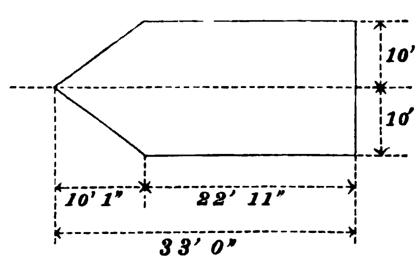
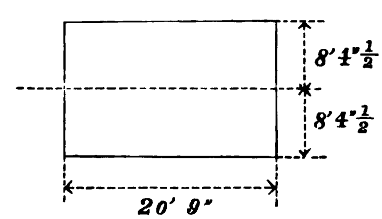


Fig. 2.
(Section A)



The values of the different factors in the fracture-formula for the section B are as follows**:—

I = Moment of the area of fracture about its middle axis
=351,560,000 (unit in inches).

$$W = \begin{cases} \text{Weight of Pier above Foundation } (=1524.8 \text{ tons}) \\ +\text{Weight of Girder and Track system } (=21.1 \text{ tons}) \\ = \text{Total Sum} = 1545.9 \text{ tons} = 3{,}463{,}000 \text{ lbs.} \end{cases}$$

f = Height of Centre of Gravity of the whole structure above Foundation = $38'\ 9'' = 465''$.

$x = 120''$.

For the tensile strength of the brick work, let us adopt a value

* The "Publications," No. 12.

** The evaluation of the quantities I, W, and f for the two sections A and B have been made by Mr. Inagaki of the Railway Department of the Formosa Government General.

of 50 lbs per sq. in., which is a little smaller than that obtained from the test pieces of the masonry of the Kiso-*gawa* railway bridge destroyed by the great Mino-Owari earthquake of 1891.* The strength of the iron rods, supposed to be uniformly distributed over the section under consideration, is equivalent to the reinforcing the masonry by 10.5 lbs per sq. in. of the area, assuming the ultimate strength of the iron rods to be 60,000 lbs per sq. in. Again, supposing the total weight of the pier and the girder and track system $(=W)$ to be uniformly distributed over the base plane B, we obtain a pressure of 43.0 lbs. per sq. in. of the sectional area. Taking together the strength of the masonry, that of the iron rods, and the compressional effect, the effective tensile strength of the column will be

$$F = 50+10.5+43.0 \text{ lbs} = 103.5 \text{ lbs.}$$

The seismic stability of the pier then becomes

$$a_1 = \frac{9800 \times 351,360,000 \times 103.5}{120 \times 456 \times 3,463,000} = 1844 \text{ mm/sec}^2.$$

(ii) Let us next take the section A, whose height corresponds to the top of the buttress. (Figs. 2 and 4.) We have:—

I = 168,502,500 (unit in inches)

$$W = \begin{cases} \text{Weight of Pier above Section } A \ (=902.1 \text{ tons}) \\ +\text{Weight of Girder and Track system } (=21.1 \text{ tons}) \\ =\text{Total Sum} = 923.2 \text{ tons} = 2,068,000 \text{ lbs.} \end{cases}$$

f = Height of Centre of Gravity of the structure above Section A $= 29'\ 10'' = 358''$.

$x_0 = \frac{1}{2} \times 16'\ 9'' = 100''\frac{1}{2}$.

The effect on the strength of the brick work of the iron rods is equivalent in this case to an increase of 16.9 lbs per sq. in. of

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* The "Publications," No. 4.

the sectional area; while the pressure of the mass above the plane of fracture is 41.3 lbs per sq. in. of it. The effective tensile strength is $F=50+16.9+41.3=108.2$ lbs per sq. in. Hence the seismic stability of the pier at the section A is

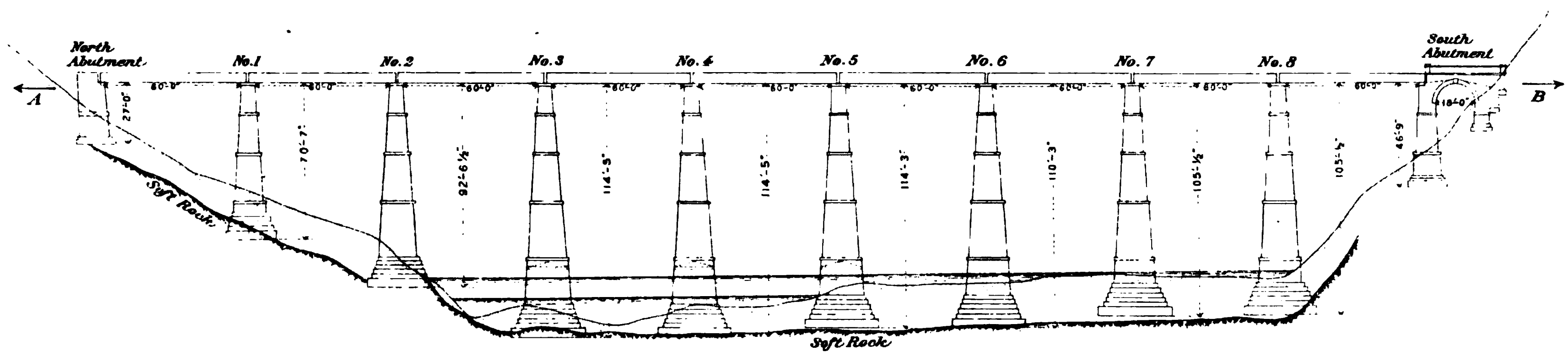
$$\alpha_2 = \frac{9800\times 168{,}502{,}500\times 108.2}{2{,}068{,}000\times 358\times 100.5} = 2404 \text{ mm/sec}^2.$$

Thus α_2 is greater than α_1 in the ratio of about 4 : 3, and the pier, which is strengthened by a buttress, is still weakest at the base, its seismic stability being $\alpha_1=1844$ mm/sec^2. As this is nearly equal to the intensity of motion in the destructive earthquakes likely to disturb the western part of Formosa, the pier in question may be considered, when the work is properly executed, to be fairly good from the seismological point of view.

Fig. 1. The Naisha-*gawa* Bridge, Formosa Railway.

Scale 1:1,000

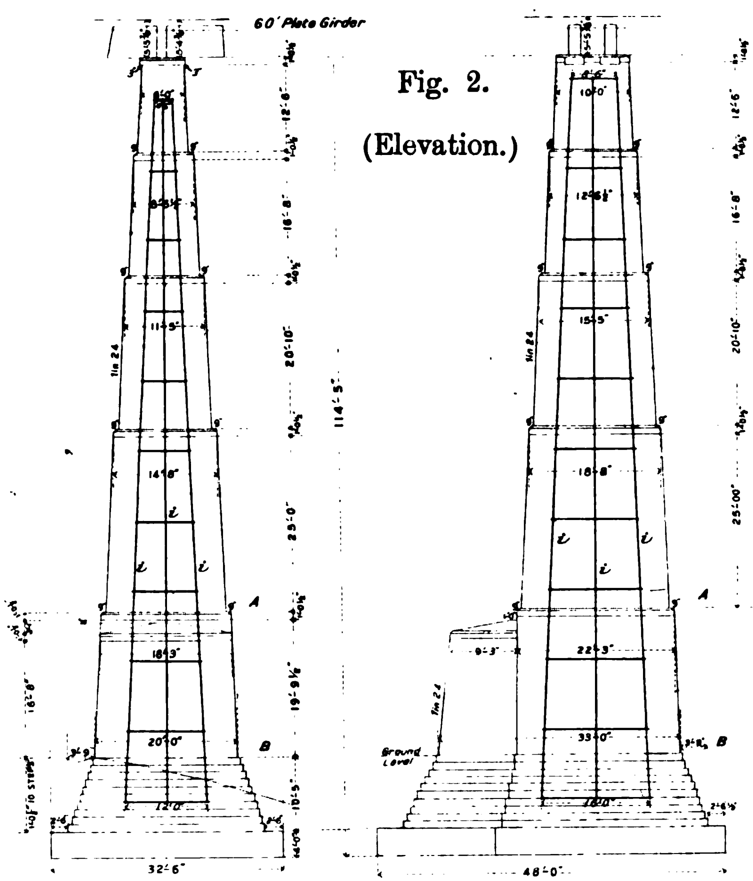
A....Taihoku End. *B*....Taichu End.



Piers Nos. 3 and 4. The Naisha-*gawa* Bridge, Formosa Railway.

Fig. 2.

(Elevation.)



Thick lines, *t*, are iron rods.

Scale 1 : 220.

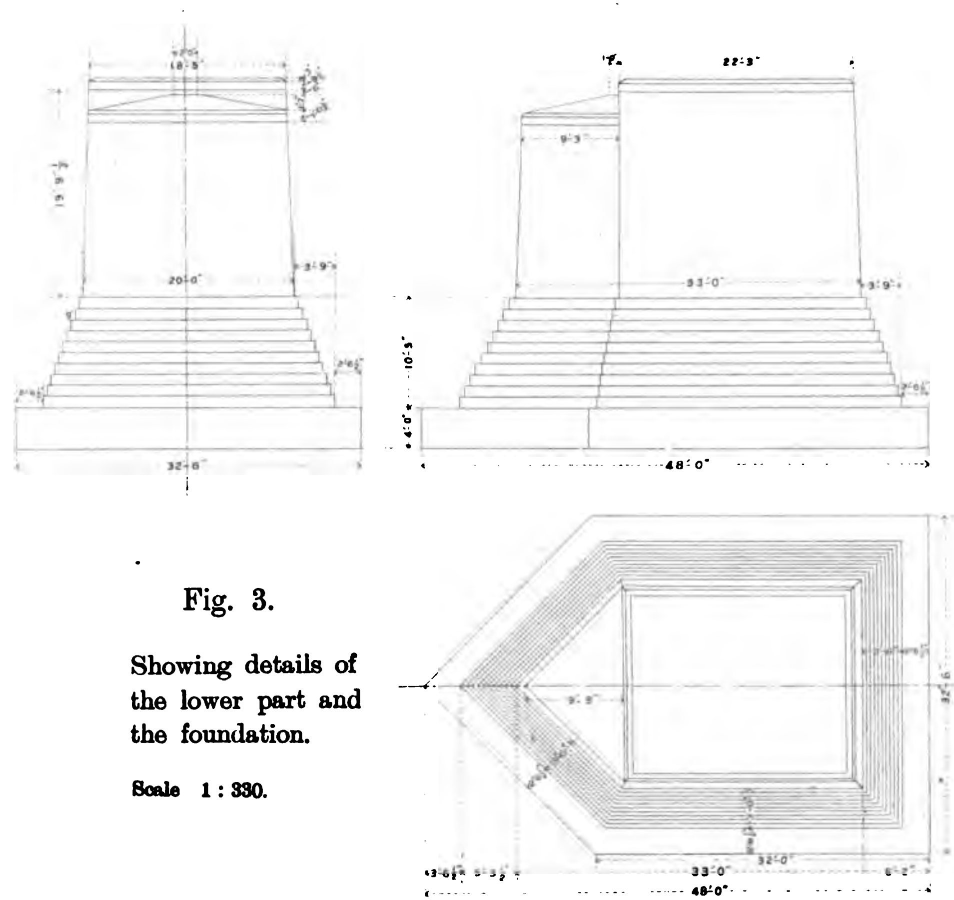


Fig. 3.

Showing details of the lower part and the foundation.

Scale 1 : 330.

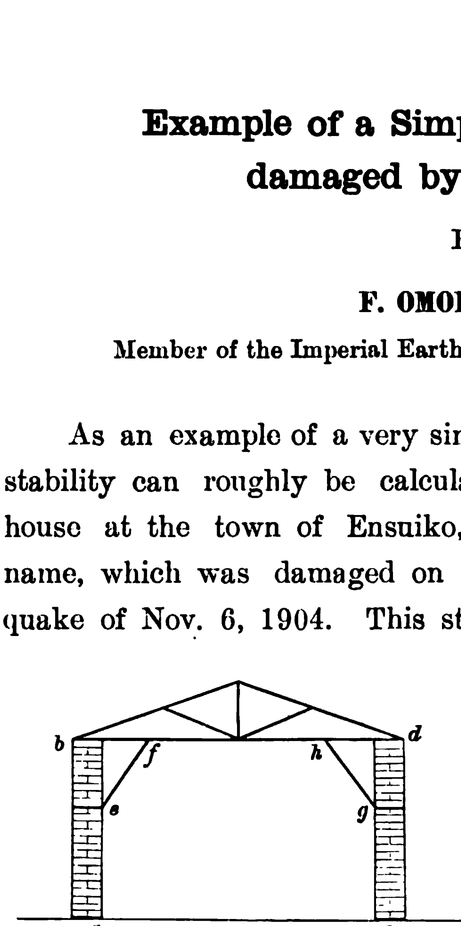
Example of a Simple Brick Structure damaged by Earthquake.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

As an example of a very simple brick building, whose seismic stability can roughly be calculated, I consider here the market-house at the town of Ensuiko, in the Prefecture of the same name, which was damaged on the occasion of the Kagi earthquake of Nov. 6, 1904. This structure consisted merely of a roof with wooden truss supported by 20 brick posts (*ab*, *cd* in the accompanying figure.) The building covered an area of 100 *tsubo*, and was 20 *ken* in length and 5 *ken* in width, the longer axis being parallel to the N–S direction.* The roof had a total area of 3,960 square *shaku*, and was covered by the tiles of the native style. As the weight per square *shaku* of the roof, truss, and the tiling, is about 15 lbs, the total weight of the roof system was about 60,000 lbs, distributed with the average amount of 3,000 lbs among the masonry posts, of which there were 10 on each side with a mutual distance of 2 *ken*. The posts consisted each of 38 layers of bricks, the height being 8.6 *shaku* (=103″), and the section



* 1 *ken* = 6 *shaku* = 1.82 metres. 1 *tsubo* = 1 *ken* square.

$1\frac{1}{2}$ bricks square, or 1.17 *shaku* (=14″) square. Assuming the weight per 1 cubic inch of the brick work to be 0.0603 lb, the weight of each of the columns will be 1,206 lbs. Thus the total pressure at the foot of each column was 4,206 lbs, giving an average amount of 21,5 lbs per square inch of the base area. This amount of compression, added to the tensile strength of the mortar joint of the brick work which is assumed to be about 20 lbs per sq. in., gives a value of 41.5 lbs per sq. in. for the effective tensile strength at base section of the columns. Again, the centre of gravity of the whole building is estimated to be at a height of 7.4 *shaku* (=2,230 mm), that is to say, only 1.2 *shaku* (=$36\frac{1}{2}$ cm) below the top of the supporting columns. This fact illustrates the importance of reducing the weight of the roof of a structure, in order to lessen the intensity of effects on the latter of the earthquake motion.

The seismic stability of the Ensuiko market-house, whose construction has been sketched above, is indicated by the acceleration (=a) of the earthquake motion, which is capable of fracturing the supporting columns at their weakest position, namely, the base. This can be calculated by the formula

$$a = \frac{4\, g x_0^3 F}{3 f\, W};$$

the value of the different constants being as follows:—

$x_0 = 177.5$ mm
$f = 2{,}230$ mm
$F = 41.5$ lbs per sq. in.
$W =$ Weight supported at the foot of the column $=4{,}206$ lbs.

The value of the acceleration a is found to be only 497 mm/sec². Such an intensity of motion is by no means that of what may

be called a "great destructive shock," but is not much different from the maximum acceleration at Hongo on the occasion of the semi-destructive Tokyo earthquake of June 20, 1894. Thus the seismic stability of the market-house under consideration will be seen to be very low. In order to make a structure in Formosa practically earthquake proof, we must raise its seismic stability to an acceleration of about 2,000 mm/sec^2.

As is to be easily imagined, all the posts of the market-house were fractured by the earthquake of Kagi of 1904 at their bases, each being also broken at or near the foot of the timber diagonal support (*ef* and *gh* in the figure.) It is hereby to be remarked that great care must be taken in the use of trusses and ties. The existence of even an apparently insignificant discontinuity, in the form and dimension, the rigidity, or the material, invariably produces a fracture or mutual destruction at the joints.

On the Duration of the Strongest Part of Motion in Destructive Earthquakes.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

The disturbance due to a large earthquake is, when observed by means of a sensitive seismograph, generally found to last several hours. The duration of the sensible part of the motion is of course much shorter. Still it may sometimes happen that at or near the epicentral district of a destructive earthquake, the ground is kept for a considerable time interval in a state of shaking, owing to an incessant occurrence of the after-shocks Thus at the Kushiro-*zaki* light-house, on the occasion of the Hokkaido earthquake of March 22, 1894, at 7h 56m pm., the lamp could not be kept lighted for the 30 minutes after the great shock on account of the almost continual succession of the tremblings; the origin of disturbance being under the Pacific at a distance of about 100 km from the coast of Kushiro and Nemuro. For the sake of reference I give next the duration of the "principal portion" of the ordinary, or non-destructive, earthquake motion, obtained from the macro-seismograph observations at Miyako (province of Rikuchu), and Kyoto.

Miyako........	Duration of Principal Portion,	0.7 sec. to 26 sec.
Kyoto	„	6.0 „ „ 20 „.

The duration of the principal portion, which according to the observations at Miyako and Kyoto varied between 0.7 and 26 sec.,

may be taken in ordinary cases to be from a few seconds to about half a minute. The monvements are, however, not uniformly large throughout the principal portion of an earthquake. On the contrary, there are usually, in the seismic motion due to a near origin, a few prominent vibrations at the commencement of the principal portion which are much larger than the others. This particular feature of motion is specially well marked in strong and large earthquakes.

The following list gives the duration of the strongest part of the principal portion for the 19 destructive, semi-destructive, and severe earthquakes in Japan, measured with the Gray-Milne-Ewing type macro-seismographs at the different stations :—

No.	Date.	Earthquake.	Place of Observation.	Duration of the Strongest Part.
1	Oct. 15, 1884	Tokyo Eqke. (severe)	Tokyo	sec. 7.0
2	June 20, 1894	Tokyo Eqke. (semi-destructive)	"	4.3
3	Oct. 7, "	Tokyo Eqke. (severe)	"	4.6
4	Jan. 18, 1895	" "	"	8.0
5	Sept. 7, 1892	Mino-Owari Eqke. (semi-destructive)	Gifu	9.5
6	Jan. 10, 1894	" "	"	6.0
7	Sept. 7, 1893	Kagoshima (Chiran) Eqke. (semi-destructive)	Kagoshima	6.0
8	Aug. 12, 1898	Fukuoka (Itoshima) Eqke. (semi-destructive)	Fukuoka	8.5
9	Aug. 31, 1896 (at 4^{h} 20^{m} pm.)	Rikuchu-Ugo Eqke. (severe)	Miyako	4.0
10	June 7, 1903	Taito Eqke. (severe)	Taito	6.9
11	April 24, 1904	Kagi " (destructive)	Tainan	8.6
12	Nov. 6, "	" " (")	"	13.0
13	March 17, 1906	Great Kagi Eqke.	"	11.9
14	April 14, 1906	Kagi Eqke. (destructive)	"	13.9
15	Jan. 11, 1906	Basshishyo and Bokusekikaku Eqke. (destructive)	"	19.6

No.	Date.	Earthquake.	Place of Observation.	Duration of the Strongest Part.
16	April 23, 1898	Origin off the NE coast of Main Island. (severe)	Miyako	19.0 sec.
17	March 7, 1899	Origin off the E. coast of Kii. (destructive)	Wakayama	19.0
18	Aug. 31, 1896	Great Riku-U Eqke.	Miyako	26.0
19	Oct. 28, 1891	Great Mino-Owari Eqke.	Tokyo	28.0

Of the above 19 earthquakes, the twelve severe, semi-destructive, and destructive shocks, namely, Nos. 1, 2,....11, and 15, were not what may be called a great earthquake, namely, extensive and very destructive seismic disturbance. Again, the three Formosa earthquakes, Nos. 12, 13, and 14, were very destructive, having caused the following amount of damage:—

Eqke No. 12 : 45 lives lost, 490 houses entirely destroyed.
„ No. 13 : 1249 „ „ , 5669 „ „ „ .
„ No. 14 : 15 „ „ , 1540 „ „ „ .

These Formosa earthquakes were, however, each quite limited in area, indicating the relative smallness of their magnitudes. Now, in the cases of the 14 earthquakes, Nos. 1 to 14, the duration of the strongest part of motion lasted 4.0 to 13.9 sec., with the average value of 8.0 seconds; being in the majority of cases less than 10 seconds. Eqke No. 15 indicated the duration of 19.6 sec.

In the two earthquakes, Nos. 16 and 17, which were large submarine disturbances, the duration were each 19 sec. Finally, the Riku-U (No. 18) and Mino-Owari (No. 19) disturbances were very great destructive shocks, the duration of the strongest motion being 26 and 28 sec. respectively.

Summary. In destructive shocks, the duration of the strongest

part of motion is generally 4 to 10 seconds. When, however, the earthquake is very great, that is to say, extensive and violent, the duration in question may be nearly 30 seconds. These results will be of use in the consideration of the destructive effects of earthquake shocks on different structures.

NOTES.

Aleutian earthquake of Aug. 17, 1906. The north Pacific earthquake of Aug. 17, 1906, occurred at about 0h 11m 44s (G.M.T.), or 28m 21s earlier than the great Valparaiso shock on the same date, the approximate position of its origin being, according to my estimation, on the southern, or convex, side of the arc of the Aleutian Islands, at $\varphi=50°$N, $\lambda=175°$E.* Had the centre of this earthquake been in the same longitude but much more southwards, say at latitude 30° N or so, the shock might possibly have been felt, or registered on the cable instruments at the Midway Island ($\varphi=28° 30'$ N, $\lambda=177°$ W). Such was, however, not the case, as will be seen from the following letters, which have very kindly been communicated to me by Dr. Otto Klotz, Director of the Astronomical Observatory of Ottawa, Canada. (F. Omori.)

"J. D. Gaines, Esq., 12th April, 1907.

Supt. Cable Station,

Honolulu, Hawaii.

My dear Mr. Gaines,

"I hope that in the following I am not asking too much of you, anyway, my excuse is that it is in the interest of Science—and that means Mankind.

"You know last August 16 about 8 P.M. at Valparaiso occurred a destructive earthquake.—The earthquake instruments showed however another quake about half an hour earlier, whose origin is placed in Lat. 30° N. Long. 107° E., say about 800 west of your station Midway.—Now what I desire to ascertain is whether at Midway the cable instruments were in any way affected either mechanically, that is, by direct pulsations or quakes, or magnetically, that is, that the magnetic field was distrubed, as shown by the syphon or electric apparatus.

* See the "Bulletin," Vol. I, No. 2.

"The time at Midway would be in the neighborhood of Noon Thursday, Aug. 16 counting time westward; I am mentioning this as Midway is so close to the anti-prime meridian where the change of date takes place; for reckoning eastward it would be noon Aug. 17.

"There should have been noticed too on that day, after noon, one or more tidal waves coming from the west due to the quake. Perhaps the diary there will disclose that phenomenon.

"I would be very glad if your Supt. (Mr. Colley), at Midway would look up the syphon records for several hours about noon and see whether any disturbance is shown. Possibly he made a note on that day about the behaviour of the instruments.

"I would have written to him direct if I knew of any mail communication with Midway, hence I throw myself on your good nature.

"It is desirable that the time should be given as accurately as possible for any disturbance that may have been recorded or noted.

Yours sincerely,

Otto Klotz."

"Commercial Pacific Cable Company.

Honolulu, H.T. July 16/07.

To Otto Klotz, Esq.,

My dear Mr. Klotz.

"Pardon the delay in answering your letter of April 12th—I have been very busy with outside work, which with the office work kept me fully occupied.

"I spoke to Mr. Colley over the wire and he looked over the slips, for several hours on each side of Noon, Aug. 16th and he says the instruments were in no way affected and no indications of tidal waves.

"I hardly expected, he would find any indications. We noticed none, during the San Francisco earthquake.

"We have felt one or two slight quakes, during the time I have lived here, but I could never discover any disturbance on the slip. A few nights ago we had a slight quake, it shook my bed, I thought of

you, noted the time, and phoned the office, to mark the slips of both instruments, so I could examine them the next morning. I could not see the slightest disturbance—I was delighted you wrote me and shall always be glad to look up anything for you.

Very sincerely,

(Sgd) J. D. CAINES."

Earthquake of Sept. 3, 1907. The following account of the earthquake of Sept. 3. 1907, is taken from the Japan Times of Sept. 25, 1907.

"*Alarming sea-quake experience of the Kinsei.* The Japanese sealing schooner *Kinsei-maru* arrived at Hakodate on the morning of the 22nd of September from the Behring Sea, having taken 743 seal skins for the season.

"The master of the vessel reports all the other Japanese sealing vessels in the Behring Sea as doing well, and having between three and four hundred seals each.

"On the 20th of August, the *Kinsei-maru* during a gale slipped a sea which smashed all her boats and did other damage, thus compelling the vessel to start for home before the close of the season.

"On the 3rd of September, while the vessel was in 53 North and 170 degrees East, heavy, severe and continued submarine earthquake shocks were felt, and which lasted for over twenty-four hours, during which the vessel sailed 120 miles. One shock lasting for three minutes was so severe that it was thought that the vessel would go to pieces. The surface of the ocean was covered with dense masses of pumice stone for a distance of over two hundred miles."

Eureka earthquake of Aug. 18, 1908. The following letter from A.H. Bell, Esq., relates to the severe local shock felt at Eureka, in California, on Aug. 18, 1908.

"My Dear Sir: Eureka, California. August 18, 1908.

The heaviest earthquake experienced since the memorable 'shake-up' of April 18, 1906, occurred this morning at 2:59 o'clock. The

vibrations lasted about fourteen seconds. Another shock of less severity was felt at 5 : 27 am., lasting about ten seconds. I am informed that this earthquake was not felt at San Francisco, the seismic motions extending about thirty miles north of Eureka and probably about the same distance to the southward. The damage done did not exceed $3000. I have just mailed detailed report to Prof. McAdie, San Francisco, California...........

Yours very truly,
Aaron H. Bell, U. S. Weather Bureau Office."

The following extract is taken from an Eureka daily paper:—

"....Weather Observer Aaron H. Bell stated this afternoon that the first and most severe quake this morning occurred exactly at 2 : 59 o'clock, and lasted about 14 seconds with vibrations from the southeast to the northwest. The violence was sufficient to stop clocks, rattle windows, and in the weather observer's office several instruments were disturbed. The greatest intensity was shortly after the beginning, gradually diminishing thereafter.

"The second earthquake this morning came at 5 : 27 o'clock, was of less violence and lasted about 10 seconds, the vibrations being upon the same direction as those of the first. Weather Observer Bell states that the quakes this morning were nothing as compared to the memorable one of two years ago in April, when San Francisco was almost wiped out of existence."

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Note on the Long-period Variations of the Atmospheric Pressure.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XLIV—XLVIII.

1. ***Introduction.*** From the discussion of the after-shocks of the Mino-Owari and other recent destructive earthquakes in Japan,* the seismic frequency has been found to have, besides the diurnal and annual variations, the periodicities approximately of the lengths of 4½ days, 9 days, 12 days, 33 days, and 3 months; amongst others, the period of 4½ days occurring very often. The present note, which is to be regarded as a supplement to my paper on the secondary causes of earthquakes (the *Bulletin*, Vol. II, No. 2), gives some account of the longer periods of variation of the barometric pressure, the object being the comparison of the seismic and atmospheric periodicities.

2. ***1st method of finding out the periodicity of barometric pressure.*** The daily or other mean barometric pressure at a given place of observation is plotted on a section paper, and the length of a period is obtained by taking the average

* F. Omori: "On the after-shocks of earthquakes," Jour. Sc. Coll., Tokyo Imp. Univ., Vol. VII, (1894). Also F. Omori: "On the Earthquakes in Formosa," Reports (Japanese) of the Imp. Earthquake Inv. Comm., No. 54 (1905).

from the mean curve drawn by free hand extended over several consecutive months. (See Figs. 1, 2, and 3.) I give next some examples relating to Tokyo, Gifu, and Mt. Tsukuba.

3. ***Barometric pressure at Tokyo, Gifu, and Mt. Tsukuba.*** As examples, I have taken the data relating to Tokyo, Gifu (province of Mino), and Mt. Tsukuba, and the average length of the different periods have been deduced from the curves, in which the ordinate is the mean barometric height corresponding to the time expressed in 1, 2, 5, or 10 days intervals. As may easily be imagined, the variation of the barometric pressure is generally very complex. In some cases, however, there is certain regularity, when the barometric variation indicates the periodicity of one kind or other. Thus, Fig. 1, which illustrates the variation of the daily mean pressure at Gifu between May 1 and Aug. 9, 1892, indicates a period of about $4\frac{1}{2}$ days. Again, in Fig. 2, which represents the same variation in 1903 at the top observatory of Mt. Tsukuba, a period of 8 or 9 days is shown between Jan. 10 and Feb. 4, and in three other epochs, while a period of about $4\frac{1}{2}$ days is shown during the rest of the year. Fig. 3 illustrates the 10-daily variation of the barometric pressure in Tokyo during the three years, 1887–1889, indicates more or less clearly a period of 3 months. The results obtained are summarized in the following table.

Time Interval.	The mean barometric pressure from whose variation the period has been deduced.	Average Length of Period.
	TOKYO.	
Oct. 1–Dec. 31, 1888.	Daily mean pressure.	4.7 days.
During the year 1888.	2-daily „	8.7 „
Jan. 1–Aug. 30, 1889.	2-daily „	32.0 „
During the 3 years, 1887–1889.	10-daily „	3 months.
	GIFU.	
Jan. 1–Sept. 9, 1892.	Daily mean pressure.	9.2 days; 4.6 days.
Jan. 1–Aug. 31, 1893.	„ „	4.6 „
Sept. 1, 1891–March 31, 1892.	2-daily „	8.6 „
May 1–Dec. 31, 1892.	2-daily „	9.3 „
During the year 1893.	2-daily „	9.0 „
Do.	5-daily „	35.0 „
Do.	10-daily „	34.0 „
Sept. 1, 1891–Dec. 31, 1892.	10-daily „	3 months.
	MT. TSUKUBA.	
Nov. 18–Dec. 31, 1902.	Daily mean pressure.	8.6 days.
Jan. 10–Feb. 4, 1903.	„ „	8.3 „
Feb. 4–March 16, 1903.	„ „	4.4 „
March 19–April 13, 1903.	„ „	8.3 „
April 17–May 5, 1903.	„ „	4.5 „
May 5–May 31, 1903.	„ „	8.7 „
Oct. 17–Nov. 5, 1903.	„ „	5.0 „
Nov. 6–Dec. 23, 1903.	„ „	7.8 „

The different periods contained in the above table may be divided into 4 groups, i, ii, iii, and iv, as follows :—

i	ii	iii	iv
days	days	days	months.
4.7	8.7	32	3
4.6	9.2	35	
4.6	8.6		
4.4	9.3		
4.5	9.0		
5.0	8.6		
	8.3		
	8.3		
	8.7		
	7.8		
Mean..**4.6** days. ..	......**8.7** days	......33 days	......3 months.

The mean values of the 4 different periods are **4.6** days, **8.7** days, 33 days, and 3 months, the first two occurring most frequently.

4. ***2nd method of finding out the periodicity of barometric pressure.*** Instead of considering the variation of atmospheric pressure at a given place as explained in the preceding §, let us find out the time interval between the successive epochs, when the whole of Japan is covered by high barometric pressure. Thus, Figs. 4 and 5 represent two consecutive cases separated by about 4 days, when the high pressure area extended over the principal Japanese islands. The mean values of the different periods in the pressure variation obtained by this method from an examination of the weather maps of Japan during the 4 years, 1900 to 1903, are given in the following table.

Time Interval.		Number of times when high pressure area extended over Japan.	Average interval between the successive high pressure epochs.	
			day	hour
Jan. 3 ; 6 am.—May. 14 ; 10 pm.	1900.	29	5	2
Sept. 29 ; 10 pm.—Dec. 28 ; 10 pm.	„	21	4	12
Jan. 2 ;2 pm.— Feb. 9 ; 2 pm.	1901.	9	4	19
Feb. 18 ; 6 am.—March 21 ; 2 pm.	„	8	4	10
March 26 ; 10 pm.—June 1 ; 10 pm.	„	14	5	4
Sept. 29 ; 10 pm.—Dec. 27 ; 10 pm.	„	24	3	21
Dec. 31 ; 10 pm. 1901—April 6 ; 10 pm.	1902.	24	4	4
April 18 ; 6 am.—May 15 ; 2 pm.	„	8	3	22
May 25 ; 6 am.—July 1 ; 10 pm.	„	5	9	10
July 17 ; 6 am.—Aug. 27 ; 10 pm.	„	5	10	10
Oct. 5 ; 10 pm. 1902—Jan. 1 ; 2 pm.	1903.	23	4	0
Jan. 5 ; 2 pm.—Jan. 24 ; 6 am.	„	5	4	16
„ 28 ; 10 pm.—May 4 ; 6 am.	„	22	4	3
May 9 ; 10 pm.—June 21 ; 10 pm.	„	8	6	6

Taking the means from the above table, we obtain the following two periods :—

$$\begin{cases} \text{(i)} & 4^{\text{d}}\ 14^{\text{h}} = 4.6^{\text{days}} & \text{(averaged from 12 cases)} \\ \text{(ii)} & 9\ 22 = 9.9 & (\ \ „ \quad „ \quad 2\ „\ ) \end{cases}$$

5. Combining the results obtained in §§ 3 and 4, the mean values of the first two periods are found to be :—

1st period .... 4.6 days.

2nd „ .... 9.3 „

Thus, the length of the 2nd period is double that of the 1st period, the latter being probably the fundamental period in the

variation of the atmospheric pressure from day to day. It is quite possible that there exist, besides the period of 9.3 days and one of about 33 days, many others of longer or shorter durations, which are probably the multiples of the 1st period. The period of the length of 3 months may be of a different origin, being one of the harmonics of the annual period.

All the four periods in the variation of the barometric pressure as above obtained are evidently similar to, and likely to be the causes of, the corresponding periods in the variation of the earthquake frequency (§ 1).

I give next a short notice respecting the after-shocks of the Taito (Formosa) earthquake of 1903, whose frequency shows fluctuations parallel to those of the barometric pressure.

6. ***After-shocks of the Taito earthquake of Sept. 7, 1903.*** The following table gives the daily mean barometric pressure at Taito (Formosa) and the daily number of the after-shocks of the strong earthquake of Sept. 7, 1903, recorded at the same place by means of an Omori horizontal pendulum of 6 times magnification.

DAILY MEAN BAROMETRIC PRESSURE AND DAILY NUMBER OF EARTHQUAKES AT TAITO (FORMOSA). SEPT.—OCT., 1903.

Atmospheric Pressure.*			Daily Number of Earthquakes.		
Day \ Month	September	October	Day \ Month	September.	October.
	mm	mm			
1	760.0	754.6	1	——	0
2	58.8	56.5	2	——	0
3	58.6	57.8	3	——	0
4	59.2	53.6	4	——	0
5	59.6	53.2	5	——	0

* With freezing point correction. Reduction to standard gravity = 1.4mm ; that to mean ea level = 0.9 mm.

Atmospheric Pressure.*			Daily Number of Earthquakes.		
Day \ Month	September.	October.	Day \ Month	September.	October.
	mm	mm			
6	58.8	58.4	6	———	0
7	57.8	58.2	7	26*	8
8	57.5	57.7	8	6	0
9	58.3	58.9	9	5	0
10	58.1	59.5	10	9	0
11	57.8	59.9	11	2	0
12	59.5	60.3	12	2	0
13	60.0	62.1	13	5	0
14	60.0	62.6	14	4	0
15	59.8	61.5	15	0	0
16	58.7	59.8	16	2	0
17	59.2	58.3	17	1	
18	60.4	57.7	18	5	
19	60.1	57.8	19	0	
20	59.0	57.9	20	0	
21	58.4	56.7	21	0	
22	58.9	55.6	22	0	
23	59.2	57.7	23	10	
24	60.4	59.6	24	4	
25	61.0	59.2	25	2	
26	59.0	58.3	26	2	
27	58.4	59.6	27	0	
28	58.2	62.6	28	1	
29	58.4	64.9	29	0	
30	56.8	64.1	30	0	
31	———	65.0	31	———	

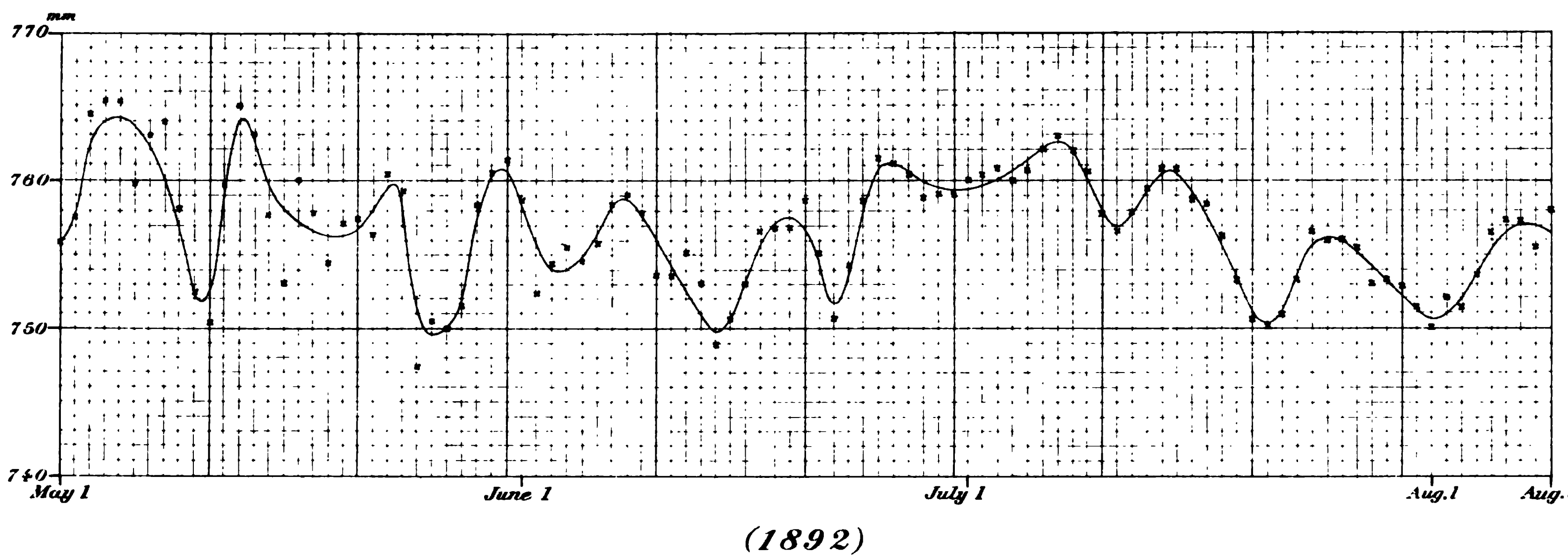
* The 1st shock took place at $2^{h}\ 59^{m}$ pm., on the 7th.

As will be seen from the graphical representations in Fig. 6, the variation of the barometric pressure between Sept. 8th and Oct. 8th (1903) indicates a period of the mean length of about 4.4 days, its maxima and minima corresponding, on the whole, respectively to the maxima and minima of the after-shock frequency.

Pl. XLIV.

Fig. 1. Variation of Daily Mean Barometric Pressure at Gifu.

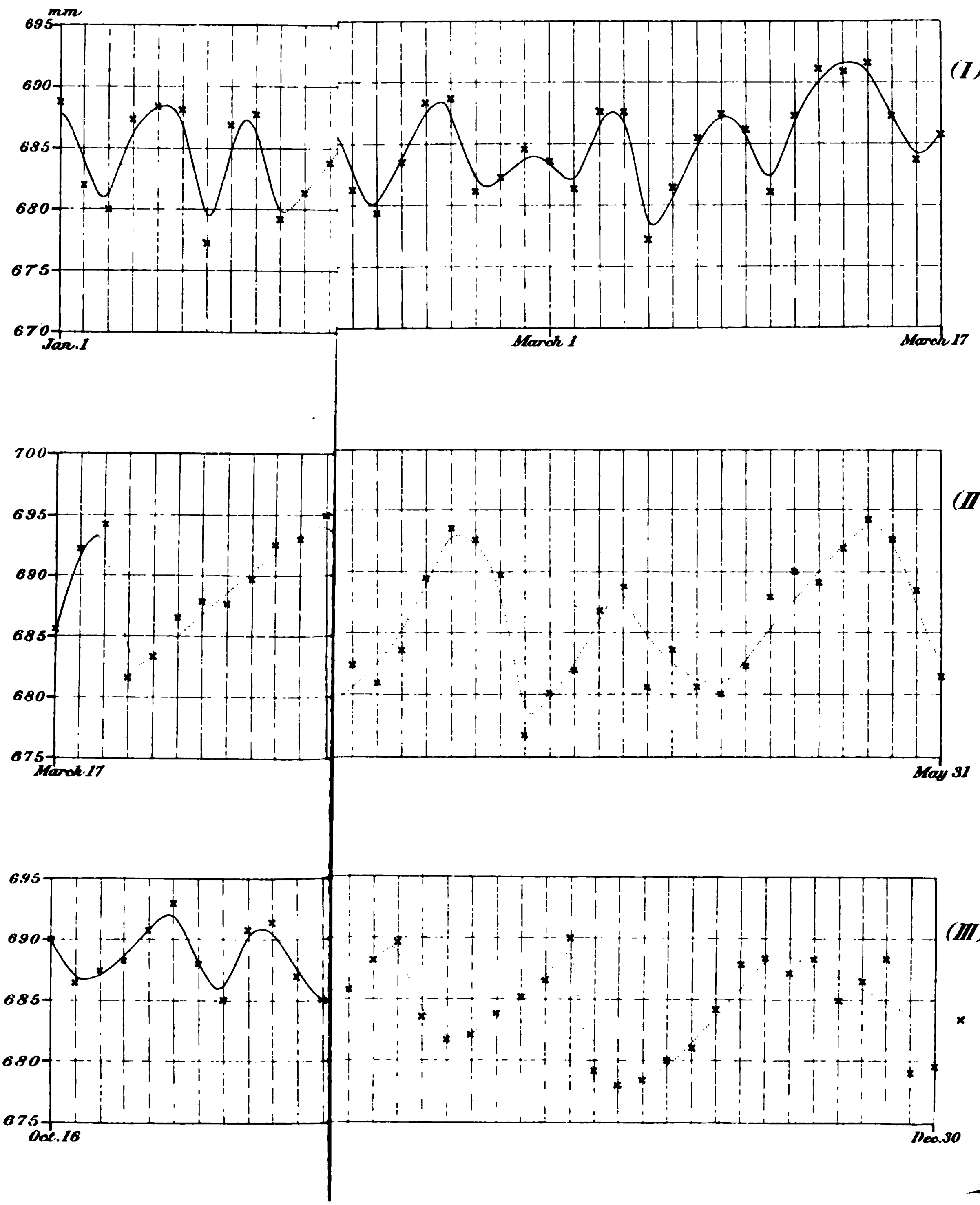
May 1 to Aug. 9, 1892.



sukuba.

B.

Pl. XLV.



sukuba.

B.

Pl. XLV.

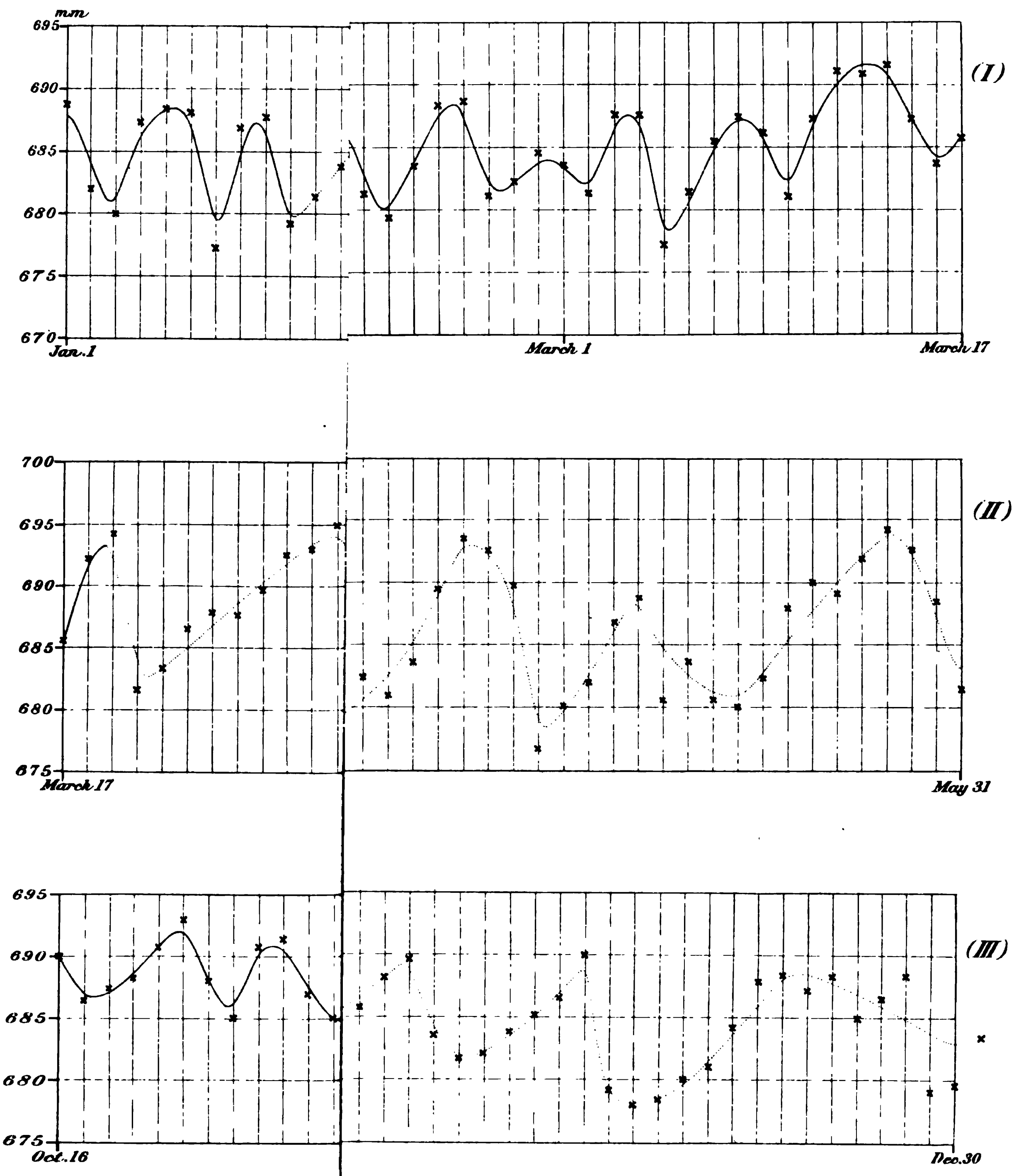
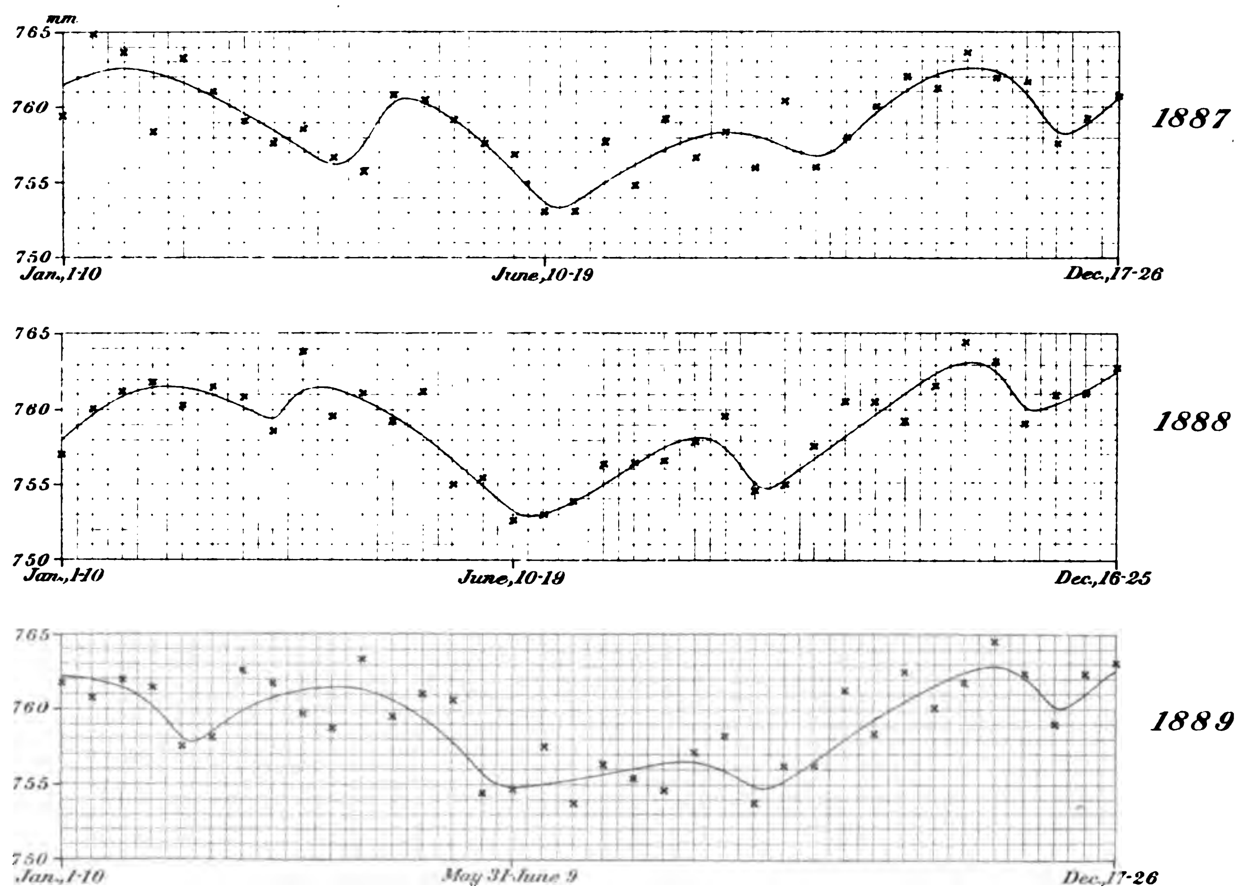


Fig. 3. Variation of 10-daily Mean Barometric Pressure in Tokyo.
1887, 1888, and 1889.



Maps showing the distribution of the Barometric Pressure over Japan.

Pl. XLVII.

Fig. 4. March 16, 1900; at 10 pm.

Fig. 8· March 20, 1900; at 10 pm.

Fig. 4.

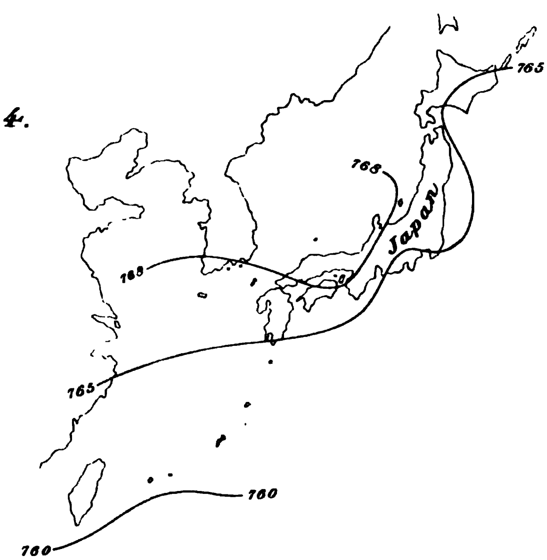
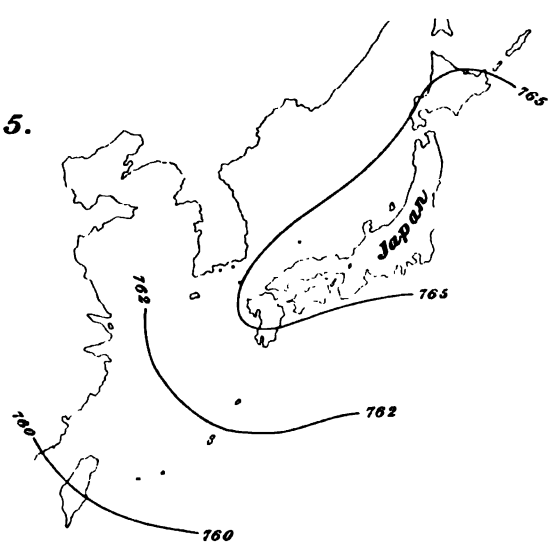


Fig. 5.



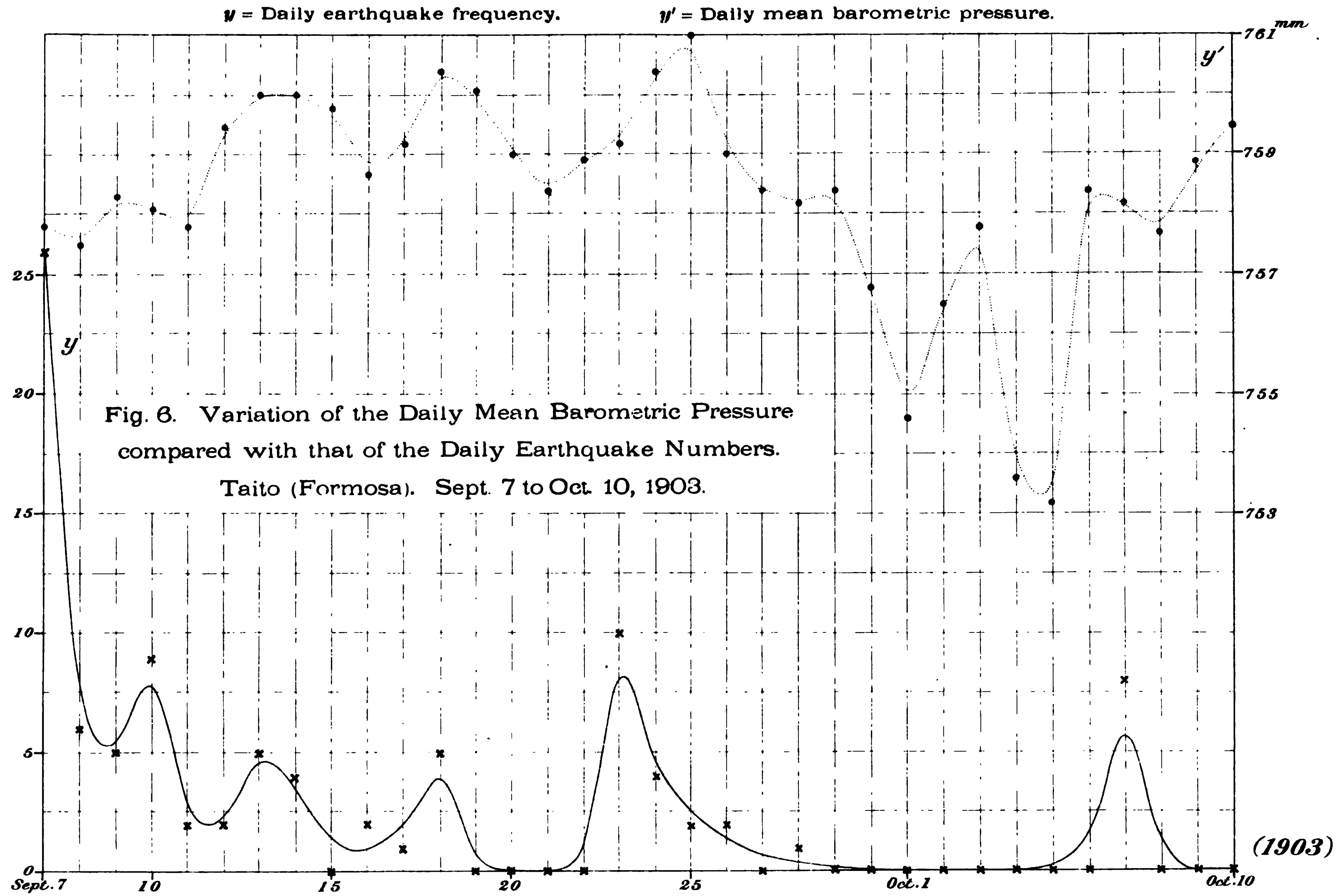


Fig. 6. Variation of the Daily Mean Barometric Pressure compared with that of the Daily Earthquake Numbers. Taito (Formosa). Sept. 7 to Oct. 10, 1903.

Experiments on the Vibration of Brick Columns.

By

F. OMORI, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. XLIX-LII.

1. *Columns.* The present note gives an account of the experiments on the vibrations of five rectangular brick columns, whose dimensions were exactly alike, each being composed of 69 layers of 4 bricks. (See Fig. 1.) The height was 15 *shaku* (=495 cm), and the sectional area was 45.5×22.5 cm. The columns, composed of bricks of superior quality of one and the same kind (日本煉瓦會社製造燒過ギ), and fixed to a single large solid foundation of concrete specially made for the purpose, had mortars of different compositions, as follows :—

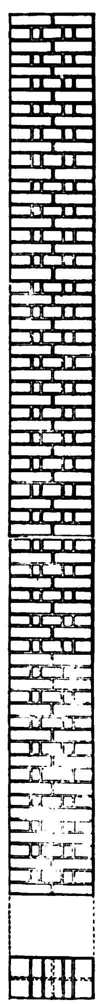
Column	No. I......	Pure cement.
"	No. II	1 part of cement, 1 part of sand.
"	No. III....	1 " , 2 "
"	No. IV	1 " , 3 "
"	No. V	4 parts of lime, 6 "

The columns, arranged in series as shown in Fig. 2, with a mutual distance of 50 cm were constructed between Nov. 25 and Dec. 18, in 1901.

2. *Experiments.* The object of the experiments carried on three months later, at the end of March 1902, was the determina-

tion of the periods of natural vibration of the different columns. For this purpose each of the latter was caused to move by being pushed or struck with hand once or several times at the top in direction normal to the broad side, being then left to vibrate freely and to gradually come to rest. The record of motion was obtained by means of a stiff pointer, which was attached to the top of the column, and to whose end was hinged a pen tracing in ink the vibrations on a record-receiver mounted on an independent staging of timbers. The diagrams obtained in this manner are reproduced in Plates XLIX to LII. The column No. V, of lime mortar, was very easily thrown into movements of a considerable amount; while the column No. I, of pure cement mortar, could be made to vibrate only slightly. Again, it happened almost always that, when one of the columns was vibrating, the neighbouring ones were also thrown into a state of motion to an appreciable degree. The following table gives for the different columns, the maximum or initial range (double amplitude$=2a$) of motion and the period of vibration during the earlier and end portions.

Fig. 1.



Brick Column. (Elevation and Section.)

Fig. 2.

Plan showing the arrangement of the columns in series.

$$\begin{cases} a=22.5 \text{ cm.} \\ b=45.5 \\ c=50. \end{cases}$$

No. of Column.	No. of Experiment.	Initial or Max. $2a$.	Average Period in the Earlier part.	Average Period in the End part.
		mm	sec.	sec.
I	1	0.8	———	0.23
	2	1.8	———	0.23
	3	4.3	0.24	0.24
	4	4.6	———	0.23
	5	7.0	0.25	0.25
	6	6.7	0.26	0.25
	7	6.3	0.26	0.25
	8	4.9	0.25	0.24
	9	8.0	0.27	0.24
	10	8.0	0.27	0.24
	11	6.9	0.26	0.25
	12	7.8	0.27	0.24
	13	5.9	0.27	0.25
	Mean.	**6.5** (1 and 2 excepted)	**0.26**	**0.24**
II	1	4.6	0.22	0.22
	2	4.7	0.24	0.23
	3	5.7	0.23	0.23
	4	5.3	———	———
	5	4.5	———	———
	6	6.7	0.24	0.23
	7	5.3	0.23	0.23
	Mean.	**5.3**	**0.23**	**0.23**
III	1	7.1	0.25	0.24
	2	6.8	0.25	0.23
	3	7.5	———	———
	4	9.5	0.27	0.24
	5	8.2	0.26	0.25
	Mean.	**7.8**	**0.26**	**0.24**

No. of Column.	No. of Experiment.	Initial or Max. 2a.	Average Period in the Earlier part.	End part.
IV	1	mm. 5.5	sec. 0.24	sec. 0.24
	2	8.5 (Column broken)	0.31	0.25
	3	13.0	0.50	0.27
	4	16.5	0.54	0.25
	5	19.0	0.62	0.26
	Mean.	8.5—19.0	0.31—0.62	———
V	1	6.7	0.42	0.33
	2	9.4	0.45	0.35
	3	7.6	0.48	0.36
	4	17.1	0.62	0.37
	5	18.7	———	0.38
	6	21.5	0.67	0.41
	7	24.0	0.77	0.40
	8	3.9	———	0.40
	Mean.	3.9—24.0	0.42—0.77	0.33—0.41

The column No. I seemed to indicate a slight lengthening of period with the repetition of the vibration experiments. Thus, in the experiments Nos.3–8, the period in the earlier part of motion varied between 0.24 and 0.26 sec., with the average of 0.25 sec.; while in the experiments Nos.9–13, the corresponding period varied between 0.26 and 0.27 sec., with the average of 0.27 sec. The period in the later part of motion seems to show also a similar, though very slight, tendency.

The same phenomenon is more markedly shown by the lime-mortar column No. V. Thus, during the eight experiments, Nos. 1–8, the period in the earlier part of motion successively

increased from 0.42 up to 0.77 sec., while the period in the later part of motion increased from 0.33 up to 0.41 sec.

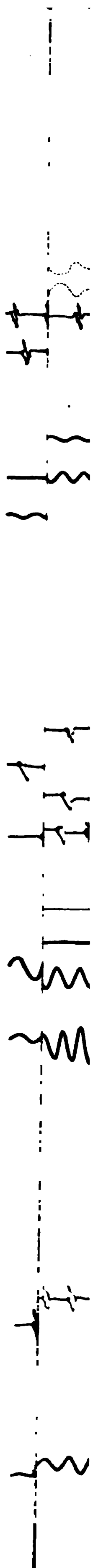
The lengthening of the vibration periods of the columns with the repetition of experiments is probably due to the formation of microscopically fine cracks at the joints and through bricks, which is equivalent to diminishing the elastic moduli of the columns without changing the mass.

3. ***Vibration of columns Nos. I-IV.*** From the above given table, it will be seen that the ranges (double amplitudes) of vibration of the different columns, although not caused by exactly one and the same amount of force, were nearly alike, the mean values varying between 5.3 and 8.5 mm. Half of the last-named limit of range of motion, which fractured the column No. IV, is to be taken as being the displacement at the top of the columns, which may break the latter at the base.

Again, the periods of vibration of the four columns under consideration were practically identical with one another, varying in the earlier, or large amplitude, part of motion only between 0.23 and 0.26 sec., and being in the later or end part between 0.23 and 0.24 sec. This uniformity of motion is quite contrary to what we should be led to expect; as the columns Nos. I, II, III, and IV, whose mortar composition varied from pure cement to 1 part of cement and 3 parts of sand, might be supposed to execute vibrations, of which both amplitude and period increase in proportion to the quantity of the sand mixed in the mortar. The apparent paradox can only be explained on the assumption that in each of the four columns, the mortar was much stronger than the bricks themselves and behaved as if it were practically incompressible, the result being that we got, in these experiments, only the vibrations due to the bricks, and not to the joints. It thus

seems that in brick works a mortar of 1 part of cement and 1 to 3 parts of sand is as good as that of pure cement.

4. ***Vibration of column No. V.*** The column No. V of lime mortar, was thrown, without being broken, up to a vibration of 24 mm, which is nearly three times the maximum motion in the cases of the other columns. This was evidently on account of the inferior quality of the mortar, in consequence of which the elasticity of the bricks themselves did not, in the vibration of the column, at all come into play. Another remarkable feature in the motion of the column No. V was the great length of the vibration period, whose maximum value was 0.77 sec. The difference of the period of vibration for larger amplitude from that for smaller one ranged in the seven experiments, Nos.1–7, from 0.09 sec. to 0.37 sec. From experiments like these we can readily imagine how a tall brick chimney with bad mortar will be thrown, on the occasion of a violent earthquake, into slow oscillations of considerable amplitude.



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